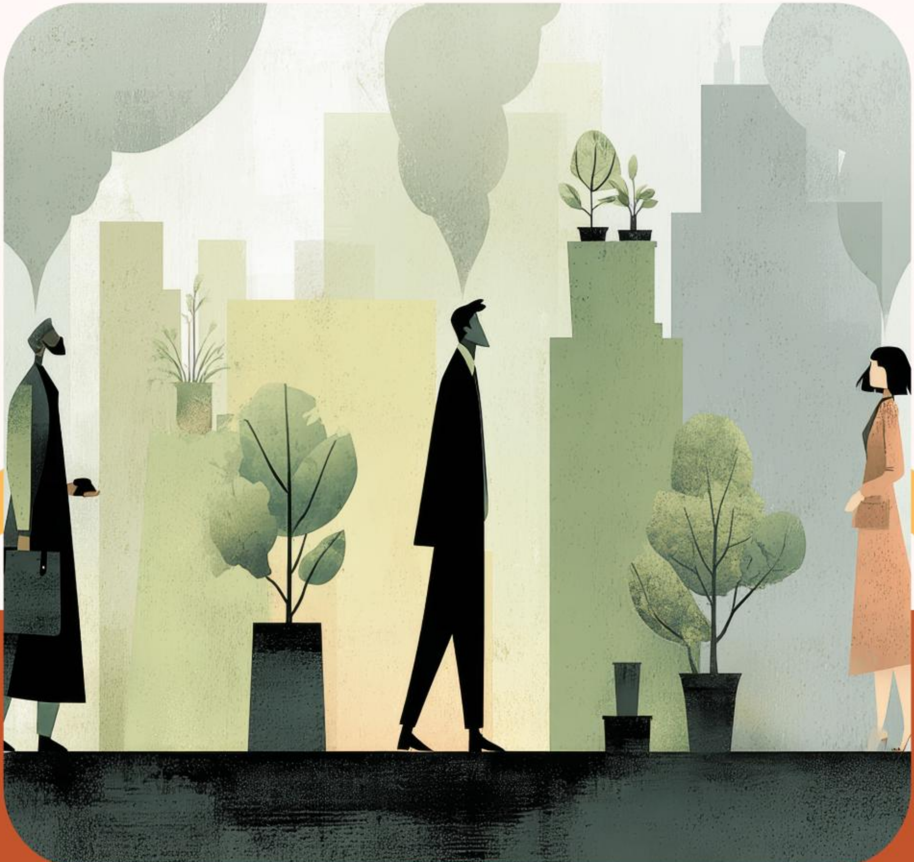
THE FUTURE OF CITIES:

LANDSCAPE, PLANNING AND DESIGN



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PREFACE

As cities around the world confront unprecedented social, environmental, and technological challenges, the disciplines of architecture, landscape, and urban planning continue to redefine the way we envision our collective future. ***'The Future of Cities: Landscape, Planning and Architecture'*** brings together a diverse collection of studies that explore innovative approaches to designing, managing, and sustaining urban environments in a rapidly changing world.

The chapters in this volume present a wide spectrum of perspectives—from the use of remote sensing and smart city solutions to the conservation of cultural landscapes and the rethinking of traditional materials. Together, these contributions reflect an ongoing dialogue among researchers and practitioners committed to creating more resilient, inclusive, and environmentally responsive cities.

We would like to extend our sincere appreciation to all authors and reviewers whose scholarly efforts have enriched this book. Our deepest gratitude goes to Prof. Dr. Atila Gül, Coordinator of the Architectural Sciences Book Series, for his invaluable guidance, encouragement, and steadfast support throughout the publication process. We also thank the publishing team for their collaboration and professionalism.

We hope that this book serves as an inspiration for academics, professionals, and students dedicated to shaping sustainable and livable cities for generations to come.

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CONTENTS

The Role of Spectral Indices in Identifying Green Spaces for Urban and Landscape Planning: A Remote Sensing-Based Approach

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1. Introduction

In today's world, due to increasing population, rapid and unplanned urbanization, the expansion of impervious surfaces, and other anthropogenic pressures, natural and semi-natural areas are undergoing a significant transformation (Zeng, Yang, & Sarker, 2022a). This transformation directly affects the quantity and distribution of urban green spaces and, consequently, has substantial implications for ecological balance, ecological sustainability, climate change, and urban aesthetics (Puplampu & Boafo, 2021; Selim, Eyileten & Karakuş, 2023a). Urban green spaces are not merely aesthetic or recreational elements; they also serve multiple critical functions such as acting as carbon sinks, filtering noise and air pollution, mitigating the urban heat island effect, regulating thermal comfort, and supporting biodiversity (Semeraro, Scarano, Buccolieri, Santino, & Aarrevaara, 2021; Karakuş et al., 2024; Çakir & Gülsoy, 2025). Therefore, the accurate identification, monitoring, and planning of green spaces within urban and landscape planning processes are essential for achieving sustainable urban development (Kowe, Mutanga, & Dube, 2021; Halecki, Stachura, Fudała, Stec, & Kuboń, 2023).

In the identification and monitoring of urban green spaces, remote sensing technologies have emerged as a prominent and increasingly popular tool in recent years, particularly in terms of spatial data production, management, and analysis (Bai, Li, Guo, Chen, & Luo, 2022; Neyns & Canters, 2022). Advances in satellite imaging systems and high-resolution sensor technologies have enabled the analysis of urban areas with high accuracy, low cost, and in a short period of time (Das & Angadi, 2022).

These developments have significantly enhanced the importance of remote sensing technologies, especially for the detection and analysis of vegetation cover. The availability of more spectral bands through advanced sensors allows for the more precise identification not only of green areas but also of various green infrastructure components such as urban agricultural zones, roadside and median strip plantings, green roofs, parks, and gardens (Shahtahmassebi et al., 2022; Li, Taubenboeck, & Zhu, 2025). In this context, the use of vegetation indices—a key component of remote sensing technologies—has become increasingly prominent. These indices enable the rapid and accurate detection of green spaces, offering significant advantages in terms of time, cost, and labour efficiency (Gupta, Kumar, Pathan, & Sharma, 2012; Chen et al., 2022).

Vegetation indices are mathematical indicators calculated by ratioing reflectance values from different electromagnetic bands. These indices are defined as spectral transformations of two or more bands from remote sensing imagery, designed to enhance the contribution of vegetation characteristics and to enable reliable spatial and temporal comparisons of photosynthetic activity and biophysical changes (Bannari, Morin, Bonn, & Huete, 1995; Xue & Su, 2017; Radočaj, Šiljeg, Marinović, & Jurišić, 2023). Additionally, these indices can indirectly reflect properties such as vegetation density, health, and moisture content (Kureel, Sarup, Matin, Goswami, & Kureel, 2022; Chowdhury et al., 2024). In particular, the near-infrared (NIR) and red bands are widely used to assess the photosynthetic activity of plant tissues. Moreover, other bands such as shortwave infrared (SWIR), blue, green, and red-edge are also utilized to highlight various characteristics of green spaces (Zeng et al., 2022b; Zhu

& Guo, 2024). For instance, different mathematical combinations of these bands are effectively used in the detection of vegetation health (Haque et al., 2024), nitrogen content (Fan et al., 2022), water stress (Zhang et al., 2021a), drought (Sang et al., 2021), vegetation density (Liu et al., 2024), chlorophyll concentration (Gao et al., 2024), and similar features. In this context, it is evident that the performance of vegetation indices varies depending on different spatial, environmental, and physical conditions.

At this point, the spatial heterogeneity inherent in urban areas emerges as a significant factor that directly influences the performance of vegetation indices. Diverse urban fabrics—such as high-density residential zones, industrial areas, mixed-use developments, green spaces of varying densities, and transportation networks—exhibit considerable variation in surface reflectance. Buildings, roof types, road surfaces, soil characteristics, and other artificial elements affect the accuracy of vegetation detection using spectral indices (Zeng et al., 2022b). Therefore, selecting spectral indices that are appropriate for the physical and structural characteristics of the study area is crucial for ensuring the reliability of the analysis.

The primary aim of this study is to comparatively evaluate the effectiveness of various commonly used vegetation indices in the detection of urban green spaces, with the goal of providing a practical guide for their application in urban and landscape planning processes. In doing so, it seeks to assist planners, landscape architects, and decision-makers in selecting the most appropriate index based on the physical characteristics of the area, vegetation density, and land use type.

Furthermore, the study aims to contribute to the enhancement of spatial decision support systems, the rationalization of green infrastructure planning, and the integration of nature-based solutions. It is also anticipated that such analyses could offer tangible benefits for strategic planning efforts by central and local governments—such as identifying city-wide green space needs, planning ecological corridors, developing climate adaptation policies, and increasing urban resilience.

Ultimately, advancements in remote sensing technologies and the diversification of spectral indices are paving the way for more data-driven, transparent, and evidence-based decision-making processes in urban green space planning. The framework proposed in this study serves as a comprehensive reference for identifying which spectral indices are most frequently used in different urban fabric types and for determining the most suitable index under varying conditions. In this way, the study aims to offer a valuable resource that provides concrete contributions to planning disciplines and public administration in the pursuit of building sustainable cities.

2. Functions of Urban Green Spaces and Their Importance in Planning Disciplines

Urban areas are undergoing a significant transformation due to various socio-cultural and economic dynamics. In this process, a noticeable decline in natural and semi-natural areas, an increase in impervious surfaces, and the disruption of ecosystem services have been observed (Semeraro et al., 2021). In this context, urban green spaces stand out not only for their social, psychological, and aesthetic functions but also for their ecological, economic, and health-related benefits (Breuste

Schnellinger, Qureshi, & Faggi., 2013). Therefore, they should be regarded as planning components of strategic importance for urban sustainability.

From an ecological perspective, urban green spaces play vital roles such as improving air quality, supporting carbon sequestration, mitigating the urban heat island effect, preserving biodiversity, and facilitating water management, thereby contributing significantly to ecosystem services (Tuğluer & Çakır, 2021; Jabbar, Yusoff, & Shafie, 2022; Selim, Eyileten, & Karakuş, 2023b; Olgun et al., 2025). Vegetation helps regulate temperatures through evapotranspiration and shading, while also absorbing rainwater and reducing flood risk (Schuch, Serrao-Neumann, Morgan, & Choy, 2017; Çakır &Tuğluer 2019).

On the social level, green spaces provide environments that positively impact the physical and mental health of urban residents. By enabling recreational activities, promoting social interaction, and fostering community cohesion, they reinforce their indispensable role in urban life (Zhou & Parves Rana, 2012). Furthermore, their economic benefits—such as increasing property values and enhancing tourism potential—should not be overlooked (Zhang et al., 2021b).

Considering all these functions, the role of urban planning and landscape planning disciplines in the context of green spaces becomes increasingly significant. The planning process aims to balance spatial justice, ecological integrity, and social well-being by determining the distribution, accessibility, quantity, and quality of green spaces within the urban fabric (Eyileten, Esendağlı, & Selim, 2022). Moreover, the development of green infrastructure solutions tailored to different urban textures enhances the contextual sensitivity of planning efforts (Selim, 2021). The integration of green spaces into planning not only addresses current needs but also lays the foundation for strategic actions that can improve urban resilience against future environmental risks (Halecki et al., 2023).

From a sustainability perspective, urban green spaces encompass environmental, social, and economic dimensions. Their environmental sustainability functions include conserving natural resources, maintaining ecosystem services, and contributing to climate change mitigation (Jennings, Larson, & Yun, 2016; Tuğluer & Çakır, 2019). In terms of social sustainability, equitable access to green spaces, protection of public health, and the promotion of social inclusion are key aspects (Teimouri, Karuppannan, Sivam, & Gu, 2019). Economic sustainability, on the other hand, can be assessed through the direct and indirect economic benefits provided by green spaces, as well as the balanced management of their maintenance and operational costs (Choumert & Salanié, 2008).

Recent scientific studies have clearly demonstrated the multifunctional roles of urban green spaces and their significance in sustainable urban development (Liu, Li, Qiu, & Liu, 2023). Numerous studies in the literature argue that, rather than focusing solely on the quantity of green spaces, greater emphasis should be placed on their quality, accessibility, and spatial distribution for a more effective planning approach (Olgun, Kahraman & Karakuş, 2022). Therefore, it is essential for urban and landscape planning disciplines to consider this multidimensional structure and integrate urban green spaces into spatial decision-making processes. This integration plays a critical role in building sustainable, resilient, and livable cities.

The initial step in incorporating urban green spaces into spatial planning processes is the accurate identification of these spaces within the complex urban fabric. While traditional methods are often time-consuming, labour-intensive, and costly, the rapid advancement of modern technologies has greatly facilitated the detection of green spaces. At this point, remote sensing (RS) and geographic information systems (GIS) offer significant advantages for the fast, accurate, and practical identification of urban green spaces.

3. Remote Sensing-Based Methods for Identifying Urban Green Spaces

Remote sensing technologies for detecting urban green spaces are increasingly supported by advanced and automated methods. Among these, machine learning (ML), deep learning (DL), artificial neural networks (ANN), and hybrid classification techniques stand out (Shi, Liu, Marinoni, & Liu, 2022; Hu et al., 2024; Ganjirad, Delavar, Bagheri & Azizi, 2025; Huang et al., 2025). These methods enable pixel-level analysis of satellite imagery or aerial photographs, allowing for more accurate discrimination of green spaces compared to traditional classification approaches (Xu et al., 2020).

Machine learning-based approaches are among the most commonly used methods for remote sensing data analysis. Advanced classifiers such as Random Forest (RF), Support Vector Machine (SVM), Gradient Boosting algorithms, and particularly LightGBM effectively classify green spaces by utilizing various spectral bands, texture features, and geometric variables. The main advantage of these methods lies in their ability to analyze heterogeneous land cover in high-resolution imagery in detail and to improve accuracy by processing a large number of variables (Rustamov, Rustamov & Zaki, 2023). For instance, by combining data from satellites such as GF-2 (Gaofen-2), and Sentinel-2, the integration of multispectral and multi-resolution datasets enables the accurate classification of small-scale green spaces.

Artificial neural networks and deep learning techniques have also gained significant importance in recent years for the detection of urban green spaces. Architectures such as Convolutional Neural Networks (CNN), U-Net, DeepLab, and SegNet enable the automatic identification of green spaces through semantic segmentation of images (Huerta et al., 2021). These methods allow for the classification of green spaces not only based on spectral information but also by utilizing spatial patterns and contextual features. When applied to high-resolution imagery, they can accurately detect detailed green elements such as green roofs, small parks, or street tree plantings (Moreno-Armendáriz et al., 2019). However, these techniques also have certain limitations, including high computational requirements and sensitivity to training datasets.

On the other hand, hybrid approaches that combine different methods have also been favoured in many studies. For example, basic classification outputs derived from spectral data are reanalyzed using machine learning or deep learning models to obtain more specialized results (Wang et al., 2023). These hybrid systems provide more accurate and generalizable outcomes within the complex structure of urban fabric and offer the advantage of adapting to different urban typologies. Such multi-layered analyses in the field of remote sensing hold significant potential to be employed as decision support mechanisms in urban planning and landscape management processes.

4. Advantages of Spectral Indices over Other RS Methods for Green Spaces Detection

Although the aforementioned remote sensing methods possess the capability to detect green spaces in urban fabric with sufficient accuracy, they also present certain challenges. Firstly, these approaches require labelled training data (ground-truth); the preparation of data, class sampling, and creation of validation sets are time-consuming and demand expertise (Hu et al., 2024). Such data vary depending on the heterogeneous nature of the urban fabric, which limits the model's generalizability. Additionally, the high number of spectral bands, high-resolution imagery, and big data processes pose disadvantages in terms of cost and processing time. The complexity of the algorithms also complicates the decision-making process. Non-spectral methods may be more sensitive to external factors such as shading, atmospheric distortions, and sensor angle. Moreover, small green spaces or micro-scale vegetation may not be accurately detected in low-resolution imagery (Shahtahmassebi et al., 2021).

Spectral indices often require less data pre-processing. They have a lower demand for extensive labelled datasets for algorithm training. Spectral indices are also well-suited for change detection over large areas and time series analyses; by calculating index values from numerous satellite images, the spatial distribution, density, and temporal changes of green spaces can be monitored (Dutta, Rahman, Paul, & Kundu, 2022). This is particularly advantageous for tracking trends and developing long-term decision support systems without the need to retrain classification models (Huete, 2012). Additionally, spectral indices offer relative simplicity, interpretability, and low computational resource requirements (Huang Tang, Hupy, Wang, & Shao, 2021). Compared to machine learning and deep learning methods, they are more practical in terms of hardware and processing power. This advantage is especially important in contexts where data infrastructure and technical capacity are limited.

5. Commonly Used Spectral Indices for Identifying Urban Green Spaces

The literature reveals that numerous spectral indices are used for the detection of urban green spaces. Among these are the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), Modified SAVI (mSAVI), Green Normalized Difference Vegetation Index (gNDVI), Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI), Transformed Vegetation Index (TVI), Perpendicular Vegetation Index (PVI), Atmospherically Resistant Vegetation Index (ARVI), Soil-Adjusted and Atmospherically Resistant Vegetation Index (SARVI), Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Normalized Difference Infrared Index (NDII), Global Environmental Monitoring Index (GEMI), Soil and Vegetation Index (SVI), Chlorophyll Index Green (CIgreen), Chlorophyll Index Red Edge (CIrededge), Weighted Difference Vegetation Index (WDVI), and Modified Chlorophyll Absorption in Reflectance Index (mCARI), among many others (Xue & Su, 2017). According to the IDB website, a total of 519 spectral indices related to vegetation have been defined, along with academic articles utilizing these indices (IDB, 2025). Each of these indices emphasizes different characteristics of vegetation in classification. The sensors used, the number of bands, and their spectral ranges enable the extraction of various vegetation-related information. Table 1 lists commonly used vegetation indices in the literature that offer ease of use, along with their formulas, advantages, and disadvantages.

Table 1. Information on Vegetation Indices Used for the Detection of Urban Green Spaces (Xue & Su, 2017; IDB, 2025).

Spectral Indices	Formula	Advantages	Disadvantages
NDVI (Normalized Difference Vegetatic Index)	(NIR - Red) / (NIR + Red)	Accurate and computationally simple methods for vegetation density estimation	In urban areas, soil and built structures can have an impact, and vegetation detection may be affected by shadows.
EVI (Enhanced Vegetation Index)	2.5 × (NIR - Red) / (NIR + 6×Red - 7.5×Blue + 1)	Less affected by atmospheric effects-more accurate in dense vegetation cover	More complex formula-requires blue band
SAVI (Soil Adjusted Vegetation Index)	((NIR - Red) / (NIR + Red + L)) × (1 + L) (L genelde 0.5)	Reduces soil influence — advantageous in sparse vegetation	The selection of the L constant can be subjective
GNDVI (Green Normalized Difference Vegetation Index)	(NIR - Green) / (NIR + Green)	More sensitive to vegetation health — can perform better than NDVI	In some sensors, the quality of the green band may be low
VARI (Visible Atmospherically Resistant Index)	(Green - Red) / (Green + Red - Blue)	Operates using only visible bands	Accuracy may decrease without NIR-susceptible to shadows
mSAVI (Modified Soil Adjusted Vegetation Index)	[2×NIR + 1 - √((2×NIR + 1)² - 8×(NIR - Red))] / 2	It is an improved version of SAVI and effectively reduces soil influence	The calculation is more complex
ARVI (Atmospherically Resistant Vegetation Index)	(NIR - (2×Red - Blue)) / (NIR + (2×Red + Blue))	Less affected by atmospheric effects	Dependent on the sensitivity of the blue band
NDMI (Normalized Difference Moisture Index)	(NIR - SWIR) / (NIR + SWIR)	Provides information about plant water content — suitable for drought monitoring	More suitable for assessing vegetation health rather than directly detecting the presence of green areas
TCI-Green (Tasseled Cap Index - Green Component)	Obtained from the Tasseled Cap transformation (satellite-specific coefficients)	The green component is prominent, enabling detailed analysis in urban areas	There are different formulas depending on the satellite, requiring preprocessing.

As seen in the Table 1, these spectral indices—developed primarily to highlight different characteristics of green spaces—essentially focus on detecting green areas. However, in urban environments, researchers must determine the appropriate index selection based on the environmental, structural, and surface characteristics of the study area. Factors such as image resolution, presence of water and moisture, shadow effects, building density, vegetation density, species diversity, and others serve as key criteria guiding researchers in choosing the most suitable indices. Figure 1 illustrates maps of some vegetation indices used for identifying green spaces within a complex urban fabric.

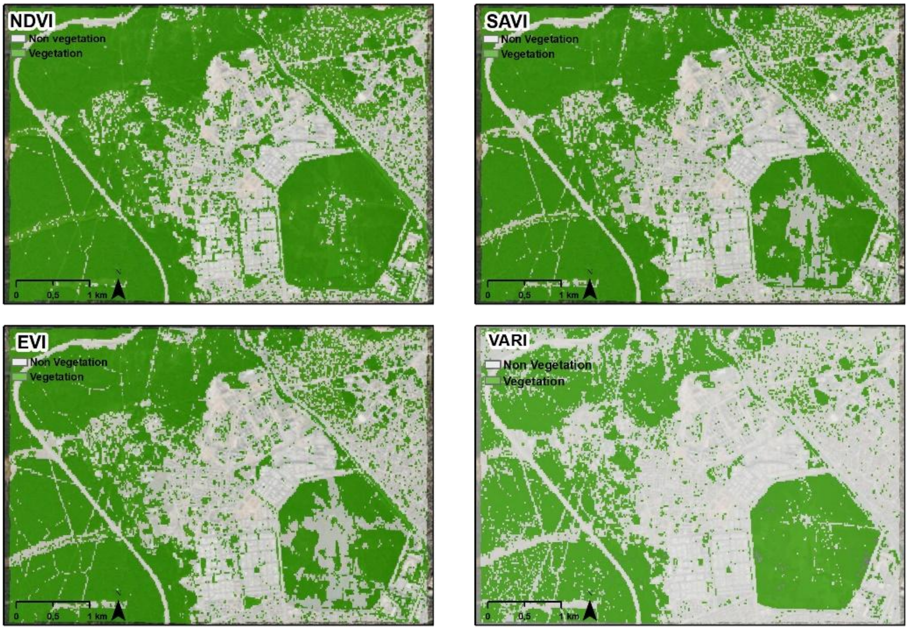

Figure 1. Maps Generated Using Selected Vegetation Indices in a Complex Urban Fabric.

In Figure 1, vegetation maps of the same study area were produced using the NDVI, SAVI, EVI, and VARI indices to classify green spaces. The differences between the EVI index, which reduces atmospheric effects, and the NDVI index, noted for its good performance in dense vegetation, are visually distinguishable on the maps. Similarly, the SAVI index, which reduces soil effects and is advantageous in sparse vegetation, appears to yield better results in this study area compared to the VARI index, which is calculated using only visible bands.

Based on these results, the effective use of spectral indices in the detection of urban green spaces depends not only on numerical data analysis but also on an accurate understanding of the physical and spatial characteristics of the study area. Urban surface cover is highly heterogeneous; green spaces can be interwoven with concrete, asphalt, and shaded structures. This situation may reduce the performance of some indices while making others more advantageous. For example, if the proportion of bare soil is high, indices like SAVI or mSAVI are more suitable, whereas in areas with dense shading and structural complexity, indices such as EVI that reduce atmospheric effects are preferable. Therefore, researchers need to conduct field observations and on-site investigations to accurately characterize land features. Strong field observation skills directly influence the success of index selection.

6. Conclusion and Suggestions

In this study, commonly used spectral vegetation indices for detecting urban green spaces through remote sensing techniques were examined, and their comparative advantages and disadvantages were evaluated. Most spectral indices can characterize vegetation based on different reflectance properties; however, each index demonstrates varying levels of performance, especially in heterogeneous environments such as urban areas. Therefore, the selection of an appropriate index requires not only technical considerations but also a decision-making process grounded in the characteristics of the study area and the landscape pattern.

Urban areas are complex environments where natural and artificial surfaces intermingle, exhibiting high variability in reflectance and frequent shading effects. In this context, although the Normalized Difference Vegetation Index (NDVI) is a widely used and practical index, it may be influenced by atmospheric effects and soil reflectance in densely built-up areas. Under such conditions, the performance of indices such as the Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), and Modified SAVI (mSAVI) should be evaluated and compared. Moreover, indices that consider water presence and moisture conditions, such as the Normalized Difference Water Index (NDWI) and Normalized Difference Moisture Index (NDMI), are particularly important for detecting green spaces with water availability. For assessing vegetation health, the performance of indices like the Chlorophyll Index Green (CIgreen) and EVI should also be specifically evaluated.

One of the key findings of this study is the decisive influence of the study area's characteristics on the selection of spectral indices. Factors such as vegetation density, the ratio of soil to concrete surfaces, shadow effects, atmospheric conditions, and image resolution directly impact the accuracy of the chosen index. Therefore, instead of a universal standard, a context-sensitive approach tailored to the local environment should be adopted when using spectral indices.

Moreover, the researcher’s strong land survey skills play a critical role in interpreting satellite data. Land surveys and ground control points help validate the results obtained from remote sensing data and prevent misclassifications. Hence, conducting an on-site examination of the study area and analyzing its physical and environmental features prior to index selection is of great importance.

This study is considered to offer direct practical contributions, especially for urban planners, landscape architects, and policymakers. Working with accurate data is fundamental for the protection, development, and sustainable management of green spaces in urban planning, forming the basis for sound decision-making processes. Proper use of spectral indices serves as a vital tool both for mapping existing green infrastructure and for long-term monitoring efforts.

In conclusion, although advances in remote sensing technologies have made spectral indices more accessible and widespread, the appropriate selection of indices should be shaped by the specific characteristics of the study area, data properties, and the researcher’s observational expertise. In this regard, the present study provides valuable guidance for both academic researchers and practitioners.

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This book chapter complies with national and international research and publication ethics. Ethics committee approval was not required for this study.

Author Contributions and Conflict of Interest Declaration

This book chapter was co-authored by two authors who contributed equally to the work, and there are no conflicts of interest to declare.

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Innovation and Design Capacity in Turkish Cities: A Geographical Perspective

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1. Introduction

There is a wide, long-standing academic literature that suggests innovation, as an economic activity, has the power to influence regional development (Romer, 1986; Tödtling & Trippl, 2011). Due to this perspective, innovation and creativity have maintained their validity since the 1980s. In addition to the economic power of innovation and creativity, their spatial dimension offers an important perspective for both urban creativity and smart city scenarios (Landry, 2000).

Although numerous studies and analyses on innovation exist in the literature, measuring the innovative capacity of cities is challenging. The use of patent numbers, especially registered patent numbers, in measuring innovation is a commonly applied method in the literature due to some advantages (Miguelez & Moreno, 2018; Tavassoli & Karlsson, 2021). The first advantage of patents is that they are accepted as a good indicator because their properties are officially registered, which provides a clear classification background. The second point is that patent data provides a unique perspective on the accumulated knowledge of cities (Feldman & Kogler, 2010).

On the other hand, another indicator of innovation and creativity is industrial design capacity, which supports product differentiation and the production of high value-added goods. In cities with a high concentration of small and medium-sized enterprises (SMEs), the adoption of industrial design enhances production quality and encourages value-added manufacturing. At the same time, design increases firms' competitiveness and their capacity to attract investment, while also strengthening local innovation ecosystems (European Commission, 2022; Whicher, Walters

& Heys, 2021). In this regard, design functions as a local development strategy that helps transform and build resilience in local economies facing global challenges (OECD, 2020). Cities with strong design capabilities often emerge as hubs for creative clusters, generating positive spillover effects in related sectors such as advanced manufacturing, technology, and services (Comunian & England, 2020). Furthermore, design enables firms to differentiate themselves in the market, thus facilitating their integration into global value chains (Chapain, Cooke, De Propris, MacNeill & Mateos-Garcia, 2010; Cunningham & Potts, 2015).

In recent studies, not only patent generation but also creativity and industrial design have become core discussions in cities and urban economic success (Florida, 2002; Scott, 2006). From this perspective, invention and industrial design are handled together to enhance innovative and creative capacity in cities.

The aim of this study is to investigate how patent generation and industrial design activities are distributed geographically across Turkish cities, thereby providing strategic implications for the future of cities. The study addresses two research questions: What is the geographical pattern of patent generation and industrial design activities in Turkish cities? Is there a significant relationship between patent generation, industrial design activities, and population size? The study compiled patent and industrial design application and registration data, as well as population data, at the provincial level. However, because cities are largely the locus of innovation and design, the term city was preferred in this article rather than province. The concentration of innovation predominantly in large cities, along with the enforcement of Law No. 6360, which incorporated all settlements within provincial boundaries into the jurisdiction of metropolitan municipalities by granting them neighborhood status, are also key factors influencing the preference for using the term city instead of province or region.

The content of this article is structured as follows: Following an introduction, the second section discusses materials and methods. This section presents the study's motivation, research questions, and the methodology employed. The third section examines the evolution of patent and industrial design applications in Türkiye over the years, their geographic distribution, and the impact of population size on this distribution. The fourth section includes concluding remarks and implications for cities of the future.

2. Material and Method

In this study, innovation and creativity capacity are measured with patent generation and design activities, which offer the opportunity to evaluate innovation ecosystems. This section begins by discussing the relative performance of Türkiye in patent and industrial design applications, followed by a description of the materials and methods used.

2.1. Relative Performance of Türkiye in Patent and Industrial Design Applications

In this part, Türkiye's relative position at the global level is revealed by comparing the performances of the leading innovation countries, the U.S., China, and Korea, with Türkiye, in terms of innovation and industrial design. For this reason, changes in the number of patent and industry design applications per 100.000 people from 2000 to 2020 in four countries are shown in Figure.1 and Figure.2. The main source of this comparison is The World Bank data.

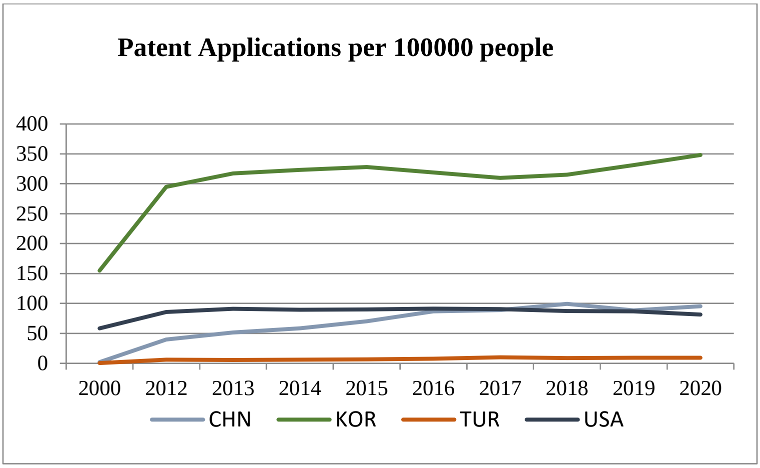


Figure 1. Patent Applications per 100.000 People (https://data.worldbank.org/, 2024).

Figure 1 displays that South Korea consistently ranks the highest in patent applications per capita. Starting at around 160 in 2000, reaching over 300 applications per 100.000 people in 2020 (Figure 1)**.** The U.S. as one of the highest patent capacity countries in the World follows at a much lower level. China began with lower figures in 2000, but showed rapid growth and narrowing the gap with the U.S. Türkiye lags significantly behind South Korea, the U.S., and China in patent applications per 100.000 people. Starting at fewer than 5 in 2000, it saw a steady but modest increase until 2020 (Figure 1). This indicates that Türkiye's patent production capacity is relatively weak**.**

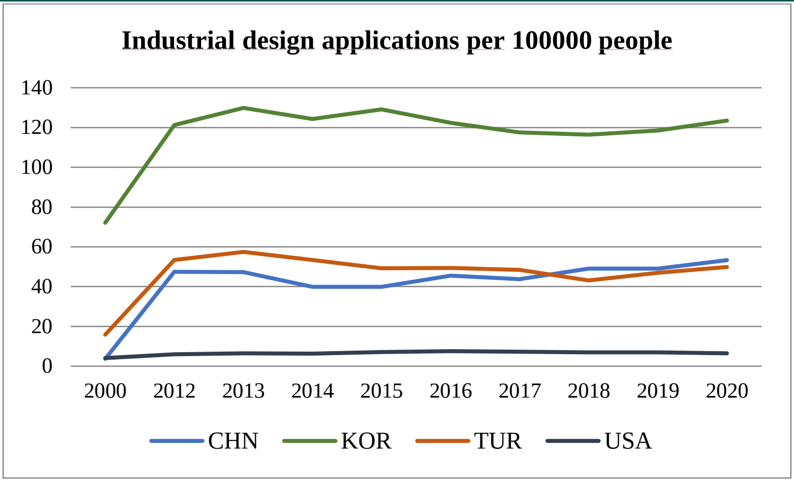


Figure 2. Industrial Design Applications per 100.000 People (https://data.worldbank.org/, 2024).

On the other hand, industrial design applications per 100.000 people shows different pattern than the patent application graph. South Korea keeps the highest position in the number of industrial design applications throughout the entire period. On the other hand, the U.S. consistently had the lowest number of industrial design applications per capita among the four countries (Figure 2).

In contrast to patents, Türkiye performs comparatively strongly in industrial design applications. Türkiye showed a significant rise between 2000 and 2012. After 2012, the numbers slightly decreased and then stabilized in the 45–50 range by 2020 (Figure 2). This situation suggests that Türkiye has a relative competitive edge in design capacity, possibly due to strengths in sectors like textiles, furniture, and consumer products. However, patent applications reveal that Türkiye is still developing its technological innovation capacity and lags behind leading economies.

2.2. Design of Methods

The intriguing result demonstrating that Türkiye's industrial design capacity is high at the global level is the primary motivation for this article. The article aims to compare patent generation and industrial design capacity at the city level in Türkiye. The main research questions in the article are: "What is the geographical pattern of patent generation and industrial design activities in Turkish cities?, Is there a significant relationship between patent generation, industrial design activities, and population size?" It is anticipated that the article's findings will provide a policy basis for the future development of creative cities and smart cities in Türkiye.

The study uses the most recent Turkish patent and industrial design data at the provincial level for 2024. Patent and industrial design application and registration data were taken from the Turkish Patent and Trademark Office (TPTO). Because cities are essentially the locus of innovation and design, the term "city" is used in this article instead of province.

In this study, to analyze the effect of city size on patent generation and industrial design capacity, cities are classified into four categories based on population size, and classified into four groups based on patent and industrial design registrations. City groups based on population size are small-sized cities (below 250.000 population), low-medium sized cities (250.001- 500.000 population), medium-sized cities (500.001- 1.000.000 population), and metropolitan cities (over 1.000.001 population). Cities are classified according to patent registrations: No capacity (0 patents)**,** low (1–6 patents)**,** medium (7–26 patents)**,** and high (27+ patents) capacity**.**

Industrial design groups are low (0 -10 design), medium-low (11-70 design), medium (71-300 design), and high (300+ design) capacity.

This study employs crosstabulation analysis to examine the relationship between city size and the capacity for patent and industrial design production in Türkiye. Crosstabs allow for the identification of patterns and associations between categorical variables, particularly focusing on how different population sizes correlate with innovation outputs. Additionally, Geographic Information Systems (GIS) were used to visualize the spatial distribution of patents and industrial designs across Turkish cities. These maps provide a clearer understanding of concentrations in innovation activities.

3. Findings and Discussion

In this section, the study findings are discussed under the subtitles of changes in patent and industrial design applications and registrations in Türkiye over the years, their geographical distribution, and the effect of population sizes of cities on the geographical distribution.

3.1. Changes in Patent and Industrial Design Applications and Registrations in Türkiye over the Years

In Türkiye, the main growth in patent applications occurred after 2004 due to the support of related institutions. Figure 3 presents the trends in patent applications and registrations from 2010 to 2024 in Türkiye. There has been a steady upward trend in patent applications, reaching approximately 10.000 applications in 2024. This result indicates a growing interest in innovation and technological development. However, the number of registered patents has remained significantly lower than applications throughout the entire period (Figure 3). Starting below 1.000 in 2010, registrations also showed an increasing trend and reached 3.374 registrations in 2024. The gap between applications and registrations might suggest a high rejection rate in the patent evaluation processes.

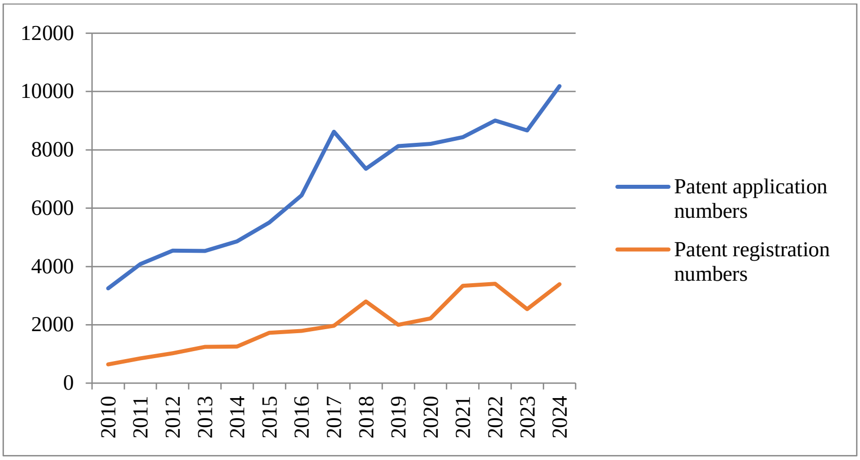


Figure 3. Patent Applications and Registrations in Türkiye by Years (TPTO, https://www.turkpatent.gov.tr/istatistikler, 2024 data).

Figure 4 shows the trends in design applications and registrations for the same time frame. Design applications increased from 2010 to 2014, and peaked around 2022 with nearly 80.000 applications. However, this spike was followed by a sharp decline in 2023 and 2024. Unlike patents, the gap between applications and registrations is relatively small, indicating a higher approval rate. Furthermore, the close alignment between application and registration trends reflects a more efficient approval system for industrial design (Figure 4).

Patent numbers show steady and long-term growth, reflecting increasing innovation capacity. The design activity has displayed a dramatic spike and subsequent decline in recent years. The decline in 2023–2024 suggests a possible policy change or saturation effect. The difference between the patents and the design activity may reflect differing market dynamics, innovation cycles, or regulatory mechanisms.

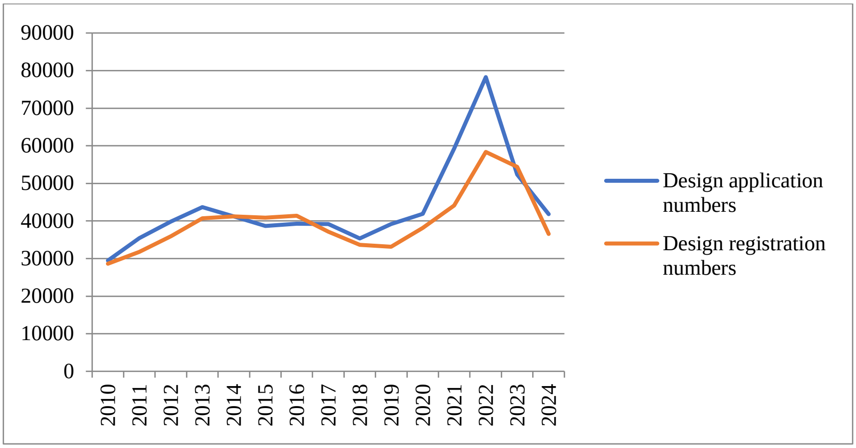
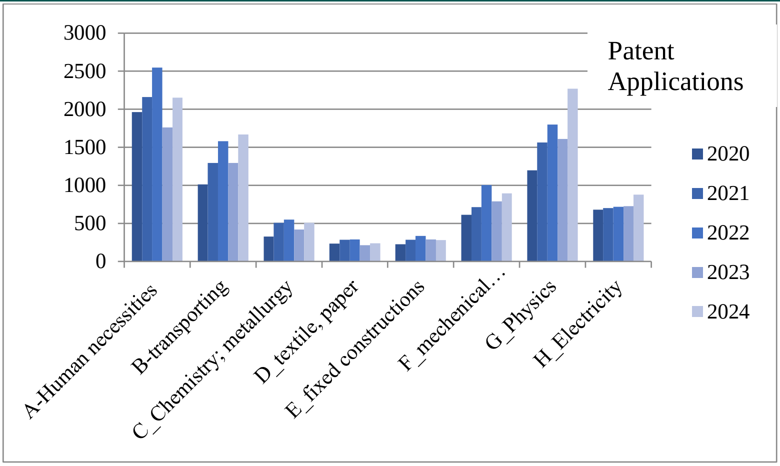


Figure 4. Industrial Design Applications and Registrations in Türkiye by Years (TPTO, https://www.turkpatent.gov.tr/istatistikler, 2024 data).

The comparison between patent applications and patent registrations across IPC technology categories from 2020 to 2024 reveals some sectoral trends (Figure 5). In both graphs, human necessities and transporting consistently lead in volume. These categories receive the highest number of applications and maintain the highest number of registrations. The strong innovation capacity in these sectors highlights the high volume of urban innovation. This data reveals key insights for future cities and urban policies.



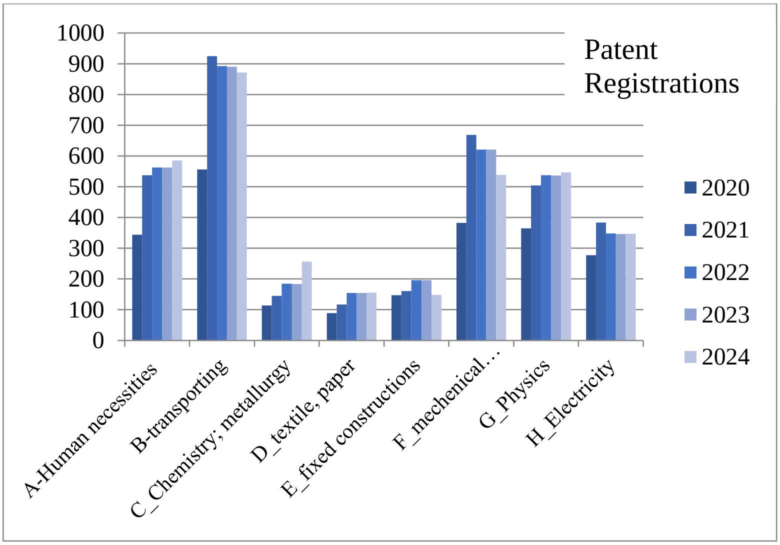


Figure 5. Patent Applications and Registrations according to IPEC, 2020-2024 (TPTO, https://www.turkpatent.gov.tr/istatistikler, 2024 data).

From 2020, onward, medical technologies and environmental innovations saw growing success in registration. This shift illustrates that global priorities in sustainability, health resilience, etc. have shaped innovation in Türkiye, like in the world. On the other hand, these shifts in patenting activity reflect how countries and cities are adapting to emerging global challenges and opportunities through innovation.

In the world, the shift during the 2020s is the acceleration of digital transformation and the adoption of sustainable design principles. Urban-related sectors, as well as those tied to urban sustainability and digitalization, stand out in the field of industrial design just as they do in patents. Among these urban sectors, one of the most striking and emerging areas is mobility and urban transport. In this sector, the electrification of vehicles and the rise of micro mobility solutions (e.g., e-scooters, e-bikes) have introduced new design priorities centered on transportation aesthetics, portability, and modularity.

Figure 6 shows the number of industrial design registrations in Türkiye across product categories according to LOCARNO from 2020 to 2024. It reveals that the highest concentration of registrations occurs in the categories furniture, decorative items, and graphics and logos, with each showing a strong upward trend, especially in 2023 and 2024. Notably, the furniture category peaks above 12,000 registrations in 2024, indicating its dominant role in design activity in Türkiye. Categories such as packaging and containers, stationery and office supplies, and building materials also exhibit steady growth, though at lower volumes. In contrast, product groups like clocks and watches, animal care products, and fluid distribution equipment maintain relatively low and stable registration numbers. Overall, the data demonstrates an interest in design in visually oriented and consumer-facing product categories.

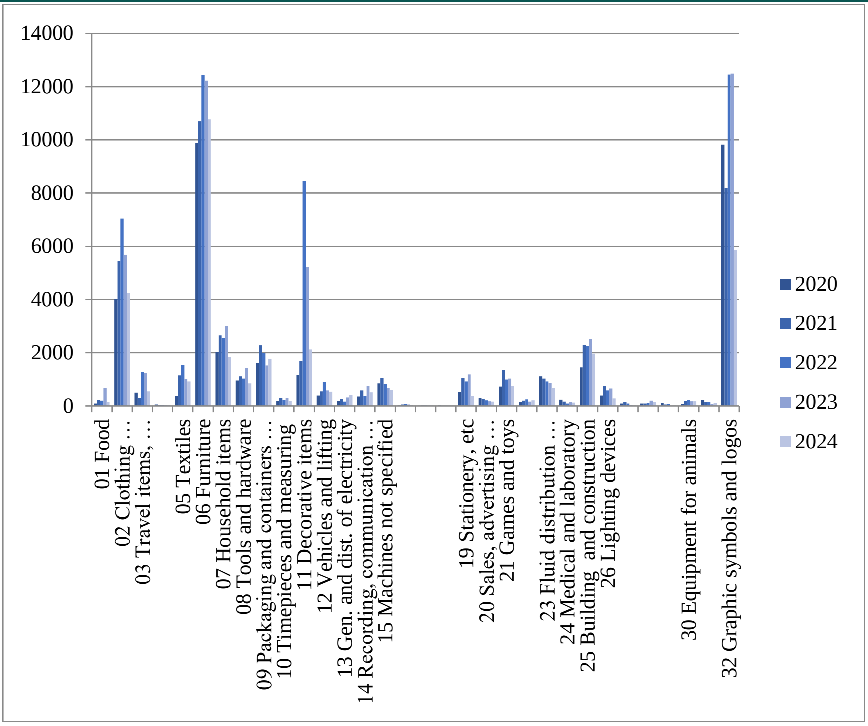


Figure 6. Industrial Design Registrations according to LOCARNO, 2020-2024 (TPTO, https://www.turkpatent.gov.tr/istatistikler, 2024 data).

This study reveals that while industrial design is prominent in traditional sectors, such as furniture and textiles, sectors like transportation and healthcare equipment, where patent numbers are relatively high, lag in terms of design numbers. However, the impact of the relatively low number of patents compared to industrial design should not be overlooked in this pattern.

3.2. Geographical Distribution and Mapping of Patent and Industrial Design Registrations in Türkiye

After examining the sectors in which patents and industrial designs are present in Türkiye, the geographical distribution of industrial design and patent registrations in these sectors illustrates the geographical pattern of innovation and creativity in Turkish cities. The average patent number is 41,6 in Türkiye in 2024. With the 1406 patent registration, İstanbul is the first city. Ankara follows İstanbul with 630 patents, and Bursa is the third province with 247 patents. Cities without any patent registration are 19,8 percent of all.

Figure 7 gives the distribution of patent registrations by province in 2024. In terms of patents, three innovative regions are developing around Istanbul, Ankara, and Izmir, while two Anatolian cities, Kayseri and Gaziantep, perform relatively better than their neighbors. In addition, there are 16 cities without patent registration, mostly located in the east and the middle of the country. It could be argued that patent production in Türkiye shows an unequal geographical distribution (Figure 7).

It is observed that the effects of the differentiation between design and innovation-based sectors on the pattern of cities in Türkiye. Therefore, industrial design registration demonstrates a different geographical distribution compared to patent registration (Figure 7; Figure 8).

The average industrial design number is 449,9 in Türkiye in 2024, ten times the number of patents. Only eight provinces exceed this critical number, with Istanbul in first place with 14.771 industrial design registrations. Bursa, Kayseri, and Ankara follow Istanbul, respectively. This ranking is quite different from the ranking in the patent data. Another interesting finding is that all cities have industrial design registrations; Erzincan has the lowest capacity with five industrial design registrations (Figure 8).

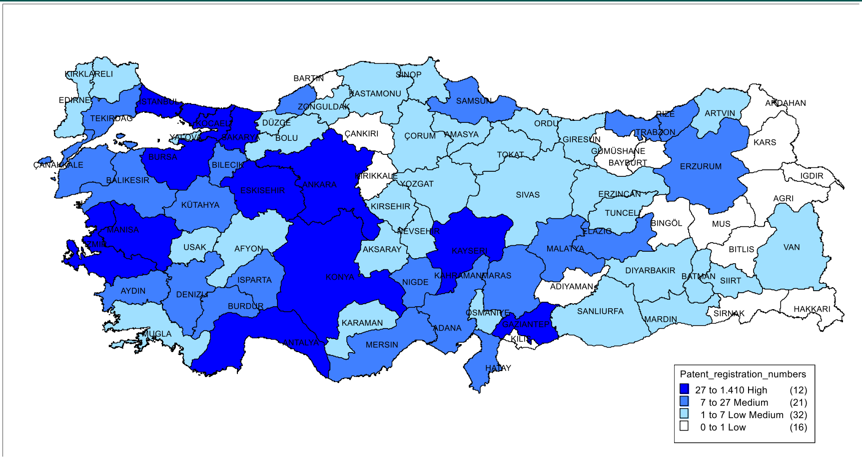


Figure 7. Geographical Pattern of Patent Registrations in Turkish Cities.

The geographic distribution of industrial design registrations presents a more widespread pattern compared to the patent map, which highlights specific centers of patent generation. While major metropolitan cities like Istanbul and Ankara dominate the patent distribution, the industrial design map demonstrates that Anatolian cities such as Denizli, Hatay, and Kütahya also play a significant role in the geographical pattern of industrial design (Figure 8).

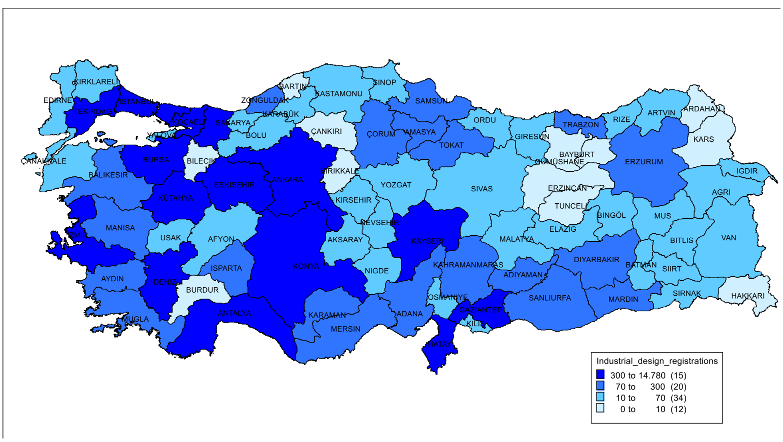


Figure 8. Geographical Pattern of Industrial Design Registrations in Turkish Cities.

It is observed that even among the lagging cities, those with no patent or low industrial design activity, notable differences exist between the two maps. The prominence of traditional sectors in industrial design contributes to the emergence of distinct spatial patterns according to the patent map (Figure 7; Figure 8). This finding suggests that, when formulating local development strategies, patents and industrial design activities should be considered separately yet evaluated as complementary indicators of innovation. Such an approach can support the development of a more effective urban strategy.

3.3. Is the Population Size of Cities a Determining Factor in the Geographical Distribution of Patents and Industrial Designs?

The differing geographical patterns in patent and industrial design registrations raise the possibility that these two crucial economic development activities may also differ depending on the population size of the cities. Table 1 presents the distribution of Turkish cities by population size and their corresponding patent registration capacity in 2024.

Table 1. Patent Generation Capacity of Cities by Their Population Size in Türkiye.

		Registered patent numbers (2024)				
Population 2024		**No patent capacity**	**Low patent capacity**	**Medium patent capacity**	**High patent capacity**	**Total**
Small sized cities less than 250.000 population	Count	7	5	1	0	13
	%	53,8%	38,5%	7,7%	0,0%	100,0%
Low Medium sized cities with more than 250.001 but less than 500.000 population	Count	7	15	4	0	26
	%	26,9%	57,7%	15,4%	0,0%	100,0%
Medium sized cities with more than 500.001 but less than 1.000.000 population	Count	2	8	7	1	18
	%	11,1%	44,4%	38,9%	5,6%	100,0%
Metropolitan cities more than 1.000.001 population	Count	0	4	9	11	24
	%	0,0%	16,7%	37,5%	45,8%	100,0%
Total	Count	16	32	21	12	81
	%	19,8%	39,5%	25,9%	14,8%	100,0%

Pearson chi-square=46,802 Significant at 0.00% level.
9 cells (56,2%) have expected count less than 5. The minimum expected count is 1,93.
No patent capacity: 0 patent Low patent capacity:1-6, Medium patent capacity:7-26, High patent capacity: 27+

Out of 81 cities, 19.8% had no patents in 2024. The majority fell into low (39.5%) or medium (25.9%) capacity categories. Only 14.8% of Turkish cities reached a high patent capacity. The Pearson chi-square value is 46.802, indicating a statistically significant relationship between city size and patent capacity ($p < 0.001$) (Table 1).

The main characteristics of small-sized cities are 53.8% of them had no patent registrations. Moreover, innovation activity appears to be very limited in these cities and none reached the high patent capacity threshold (Table 1). Over 57% of low medium-sized cities fell into the low-capacity category and similar to small cities no one in this group reached the high patent generation capacity. Among larger medium-sized cities 5.6% reached high patent capacity, showing an upward trend in innovation performance with increasing population size. The only one city in this group is Eskişehir. Metropolitan cities dominate in innovation performance, 45.8% had high patent capacity (Table 1). Indeed, none of the metropolitan cities had zero patent registrations.

Therefore, it is advocated that there is a strong positive correlation between city size and patent capacity in Türkiye. While larger cities, especially metropolitan cities, are significantly more likely to generate higher numbers of patents, smaller cities lag behind and may require innovation policies and capacity-building initiatives.

In 2024, industrial design activity in Türkiye shows a clear positive correlation with city size. Small cities are largely limited in design capacity, over 60% fall into the low-capacity category, and none reach medium or high capacity levels (Table 2). Low medium-sized cities mostly remain in the medium-low capacity group, with no cities attaining high capacity. 54.2% of metropolitan cities fall into the high-capacity category and 41.7% into the medium category, with virtually no representation in the lower tiers (Table 2).

Table 2. Industrial Design Generation Capacity of Cities by Their Population in Türkiye.

Population 2024		Registered industrial design numbers (2024) Low industrial design capacity	MediumLow industrial design capacity	Medium industrial design capacity	High industrial design capacity	Total
Small sized cities less than 250.000 population	Count	8	5	0	0	13
	%	61,5%	38,5%	0,0%	0,0%	100,0%
Low Medium sized cities with more than 250.001 but less than 500.000 population	Count	5	18	3	0	26
	%	19,2%	69,2%	11,5%	0,0%	100,0%
Medium sized cities with more than 500.001 but less than 1.000.000 population	Count	0	9	7	2	18
	%	0,0%	50,0%	38,9%	11,1%	100,0%
Metropolitan cities more than 1.000.001 population	Count	0	1	10	13	24
	%	0,0%	4,2%	41,7%	54,2%	100,0%
Total	Count	13	33	20	15	81
	%	16,0%	40,7%	24,7%	18,5%	100,0%

Pearson chi-square=70,648 Significant at 0.00% level. 10 cells (62,5%) have expected count less than 5. The minimum expected count is 2,09.
Low industrial design capacity: 1 -10 Medium Low industrial design capacity:11-70
Medium industrial design capacity:71-300 High industrial design capacity: 300+

These patterns are statistically significant, as evidenced by the Pearson chi-square test result ($\chi^2 = 70.648$, $p < 0.001$), confirming a strong association between city size and industrial design performance. Overall, the data reveal a spatial concentration of industrial design activity in metropolitan cities, highlighting regional disparities in innovation output.

The 2024 data for Türkiye reveal parallel yet distinct patterns in the spatial distribution of patent and industrial design capacities. In both domains, metropolitan cities consistently outperform smaller cities. These findings emphasize the central role of urban scale in driving both technological and design-related innovation, and the role of innovation policies to support smaller and medium-sized cities. In other words, developing industrial design capacity in different sectors is an important development strategy, especially for medium-sized cities.

4. Conclusion and Suggestions

This study has revealed the critical role cities play in shaping national industrial design and innovation performance in Türkiye. It demonstrates that while metropolitan cities continue to serve as hubs of innovation, smaller and medium-sized cities remain potential, particularly in industrial design, which is closely linked to traditional craft-based industries such as textiles and furniture. The findings emphasize that industrial design holds unique promise for stimulating local economic development in these cities, due to its lower dependence on advanced technological infrastructure and its strong cultural and creative roots.

However, the geographically unequal distribution of innovation and design capacity points to the need for more inclusive, regionally tailored development strategies. A place-based approach, one that recognizes the specific assets and limitations of different urban scales, is also essential for building resilient and balanced innovation ecosystems. Investments in local knowledge institutions, social and creative infrastructure, innovation-enabling environments (such as universities, design hubs, incubators, and public spaces), and quality of urban life, urban security (Armatlı-Köroğlu & Reid, 2025) will be critical in this regard.

To close the gap between patent and design capacity, strategic efforts should focus on integrating R&D with creative industries, thereby enabling the transformation of creative potential into innovation. Urban sectors such as mobility, health care, and urban transport require design-led innovation to develop future-oriented, smart, and sustainable cities.

Ultimately, as cities transition toward more innovation and design driven futures, multi-level innovation strategies (national, regional, and local levels) will be vital. While national-level analyses provide a foundation for macro and meso policy-making, future research focusing on intra-urban dynamics will be equally crucial for guiding micro-scale interventions. Supporting innovation and design across all urban layers will be key to fostering creative and sustainable urban development in the cities of tomorrow.

Acknowledgements and Information Note

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Temporal Change of Land Use in Afyonkarahisar Province

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1. Introduction

The rapid increase in the world's population, especially since the second half of the 20th century, has led to significant changes in land use patterns, along with processes such as urbanization, industrialization, and intensification of agricultural activities. The growing population's basic needs for food, shelter, and transportation are increasing pressure on natural areas; this pressure is causing forests, pastures, and natural ecosystems to be replaced by agricultural and residential areas (Naranjo Gómez, Lousada, Velarde, Castanho & Loures 2020). These transformations have profoundly affected socio-ecological systems, not only in terms of the physical environment but also through consequences such as the disruption of ecological balance, loss of biodiversity, increased carbon emissions, and the undermining of sustainability goals.

Monitoring and analyzing changes in land use is of great importance for sustainable environmental management and planning. In this context, achieving environmental sustainability, which aims to ensure a sustainable food supply and the conservation of natural resources, is not only possible through the monitoring of changes in land use, but also through the implementation of integrated and sustainable management approaches that take these changes into account (Mustard, Defries, Fisher & Moran, 2012; Guzha, Rufino, Okoth, Jacobs & Nóbrega, 2018).

In this context, Geographic Information Systems (GIS) are widely used in monitoring and modeling land use changes by providing high-accuracy spatial data production at low cost over large areas (Rogan & Chen, 2004; Polat & Yalçın, 2020; Kraeski et al., 2023). One of the data sources frequently used in GIS-based analyses, the "Coordination of Information on the Environment (CORINE)" land use data, is a systematic monitoring program developed by the European Environment Agency (EEA) that enables the monitoring of land use dynamics across the European continent, including Turkey (CORINE, 2025). First published in 1990, CORINE data has been updated in 2000, 2006, 2012, and 2018, enabling temporal comparisons of changes in land cover. The database is prepared at a scale of 1:100,000 and covers 39 countries and an area of approximately 5.8 million km². The data includes 44 different land cover and use classes; the minimum mapping unit is 25 hectares, and the minimum mapping width is 100 meters (CORINE, 2023).

The CORINE database has been widely used in studies analyzing land use change in Turkey and around the world (in areas such as urban planning, urbanization, agricultural expansion, forest areas, natural area losses, environmental issues, etc.) (Popovici, Bălteanu & Kucsicsa, 2013; Bayar & Karabacak, 2017; Cuceloglu, Abbaspour & Ozturk, 2017; Özkök, Tok, Gündoğdu, & Demir, 2017; Polat & Yalçın, 2020; Üyük, Uzun, & Çardak, 2020; Selçuk, Cebeci, Köker & Yılmaz 2021; Türker, 2021; Aksoy, Demir, & Yıldız, 2022; Karaoğlu & Erdel, 2022; Nacar & Karademir, 2022; Mingarro & Lobo, 2023; Aytop & Pınar, 2024; Aytop, 2024; Sarı & Vapur, 2025). In this regard, analyzing long-term land use changes is critical for the development of sustainable planning policies.

The aim of this study is to analyze land use changes that occurred between 1990, 2000, 2006, 2012, and 2018 in Afyonkarahisar province using CORINE data. The period under review is significant in that it covers a process of rapid urbanization and regional development policies in Turkey. The analysis identified the land classes present in the region, the areas they cover, and their spatial and temporal changes, and discussed the possible causes and consequences of these changes. It is anticipated that the findings will contribute to various fields, including urban planning, sustainable land management, strategies for protecting ecological balance, and the appropriate use of land. In this context, the study is expected to provide scientific input for the development of policies aimed at environmental sustainability.

2. Material and Method

Afyonkarahisar province, with an area of 14,570 km² and a population of 750,193 (2024), is located in the Inner Western Anatolia Region of the Aegean Region (URL 1). The province is bordered by Eskişehir to the north, Konya to the east, Uşak to the west, Burdur to the south, Kütahya to the northwest, Isparta to the southeast, and Denizli to the southwest (Figure 1). Afyonkarahisar, with an elevation of 1,034 meters above sea level, is situated between 37°45' and 39°17' north latitude and 29°40' and 31°43' east longitude. Afyonkarahisar province has an administrative structure consisting of a total of 18 districts, including the central district, 42 towns, and 420 villages (URL 2). The fact that major transportation arteries, including highways and railways, pass through Afyonkarahisar makes the province a strategic crossroads. With this location, Afyonkarahisar serves as an important center connecting different regions and where transportation networks intersect. The province's economic structure is shaped by tourism (health, cultural, and religious tourism), industry (particularly marble and food industries), agriculture, and livestock farming, and it possesses significant potential in these areas at both the regional and national levels. Although Afyonkarahisar is located in the

Aegean Region, it exhibits continental climate characteristics due to its position in the Inner Anatolia transition zone. Elevation and distance from the sea intensify the harshness of the climate; however, air currents from the Aegean and Mediterranean partially moderate the climate. Summers in the province are hot and dry, winters are cold and snowy, and spring months are mild and rainy.

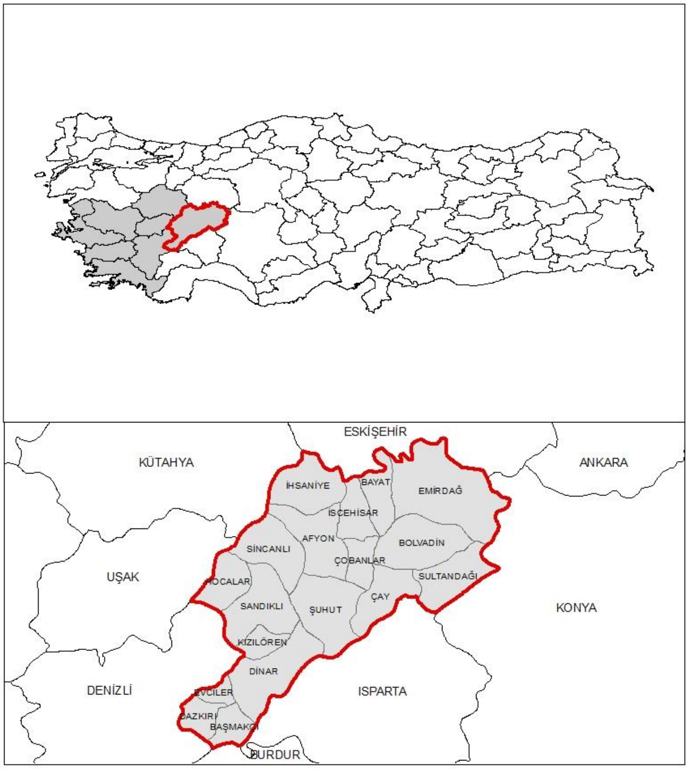

Figure 1. Location of the Study Area.

In this study, land use data within the administrative boundaries of Afyonkarahisar province were obtained from the CORINE database provided by the EEA for the years 1990, 2000, 2006, 2012, and 2018. These data consist of vector data in the ESRI Geodatabase format with a spatial resolution of 100 meters, in the shapefile (shp) format. The administrative boundaries of the province were obtained from the General Directorate of Mapping. In the CORINE database, land use is defined under a three-level classification system: 5 classes at the first level, 15 classes at the second level, and 44 classes at the third level (ELD/CLCD, 2016). In this study, new classes suitable for the analysis objectives were created based on the existing CORINE classes, and the maps were reorganized using geographic information system (GIS) software. Thus, temporal land use/land cover change maps were obtained for the relevant years. The new classification created seven classes: residential areas, agricultural areas, forest areas, pasture areas, water bodies, bare rocks, and other areas.

According to data obtained from the CORINE database, thematic maps showing temporal land use were prepared for the province of Afyonkarahisar for the years 1990, 2000, 2006, 2012, and 2018. In the GIS environment (ArcMap 10.7), the land uses obtained for each year in Afyonkarahisar province were calculated in terms of area (ha) using the “calculate geometry” module. In addition, the ratios and area values of land use classes within the total surface area of Afyonkarahisar province are presented in tables.

3. Findings and Discussion

According to the CORINE database, the temporal change in land use between 1990, 2000, 2006, 2012, and 2018 was examined for the province of Afyonkarahisar, and the area and ratio distributions calculated based on maps obtained in the GIS environment are presented in Table 1. When the data in Table 1 is examined, it is seen that more than 46% of the province consists of agricultural areas, while approximately 34% consists of forest areas.

Table 1. Afyonkarahisar Province Land Use Data.

	1990		2000		2006		2012		2018	
	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)
Residential Areas	19,2	1,3	21,0	1,5	22,6	1,6	24,0	1,7	24,7	1,7
Agricultural Areas	661,1	46,2	663,4	46,4	664,0	46,4	665,8	46,6	665,8	46,6
Forest Areas	479,5	33,5	479,6	33,5	496,5	34,7	496,8	34,7	496,1	34,7
Pasture Areas	39,7	2,8	38,7	2,7	44,2	3,1	39,0	2,7	38,7	2,7
Bare Rocks	185,8	13,0	185,4	13,0	159,3	11,1	160,4	11,2	160,3	11,2
Water Bodies	18,3	1,3	18,6	1,3	27,3	1,9	27,1	1,9	27,2	1,9
Other Areas	26,9	1,9	23,8	1,7	16,3	1,1	16,8	1,2	17,12	1,2

To evaluate the temporal change in land use data for Afyonkarahisar province on an annual basis, maps prepared for the periods 1990-2000, 2000-2006, 2006-2012, and 2012-2018 periods are presented in Figures 2, 3, 4, and 5, respectively. Table 2 provides information on the number of hectares of change in each land class during the periods 1990-2000, 2000-2006, 2006-2012, and 2012-2018. According to the data in Table 2, settlement areas showed a continuous increase in all four periods, while agricultural and forest areas only decreased between 2012 and 2018. This change highlights the disruptive effects of anthropogenic activities on natural ecosystems (Naranjo Gómez et al., 2020; Aytop, 2024). The unplanned and uncontrolled conversion of agricultural areas into residential areas leads to the loss of agricultural land in terms of both quantity and quality, and this situation is considered one of the most fundamental factors threatening agricultural sustainability in the long term (Koç, 2018; Altın & Yılmaz, 2020; Kocur-Bera & Pszenny, 2020). The inability to control urban sprawl has led to the irreversible conversion of productive agricultural land into built-up areas, posing significant risks to both food security and environmental balance (FAO, 2017). The destruction of forest areas through various human activities and their conversion into agricultural land or settlement areas is considered one of the main causes of the decline in forest cover (FAO, 2020). In particular, unplanned rural settlement expansion and pressures to increase agricultural production areas lead to the fragmentation of natural forest ecosystems and loss of biodiversity (Ünalan & Gülersoy, 2021). This transformation process also causes a decrease in carbon sink areas and an increase in negative effects on climate change. Pasture areas increased by only 5,545 ha between 2000 and 2006, while showing a decreasing trend in other periods. In water bodies, a decrease was observed only between 2006 and 2012, while increases were observed in other periods.

Table 2. Data on Changes in Land Use in Afyonkarahisar Province by Year.

	Residential Areas (ha)	**Agricultural Areas (ha)**	**Forest Areas (ha)**	**Pasture Areas (ha)**	**Bare Rocks (ha)**	**Water Bodies (ha)**	**Other Areas(ha)**
1990-2000	1,761	2,297	38	-1,034	-396	335	-3,093
2000-2006	1,663	543	16,930	5,545	-26,106	8,674	-7,526
2006-2012	1,373	1,833	266	-5,218	1,166	-157	517
2012-2018	685	-29	-689	-344	-144	97	285

Figure 2 shows land use maps created for the years 1990-2000. During this ten-year period, the most significant increase occurred primarily in agricultural areas, totaling 2,297 ha. The next most significant increase was observed in residential areas, totaling 1,761 ha. Additionally, the decrease in other areas by 3,093 ha and the significant decrease in pasture areas by 1,034 ha are noteworthy.

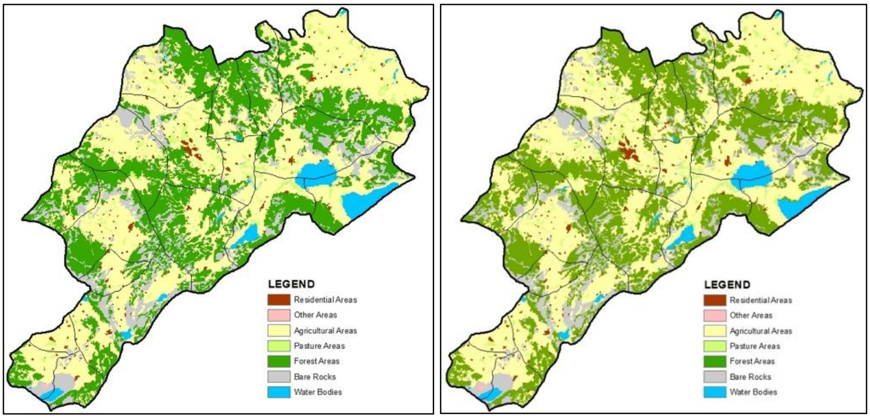

Figure 2. Land Use in 1990 and 2000.

Figure 3 shows land use maps created for the years 2000-2006. During this six-year period, the most significant increase occurred primarily in forest areas, totaling 16,930 ha. The next most significant increases were in water bodies (8,674 ha), pasture areas (5,545 ha), and residential areas (1,663 ha). Along with these, there were notable decreases in bare rock areas (26,106 ha) and other areas (7,526 ha).

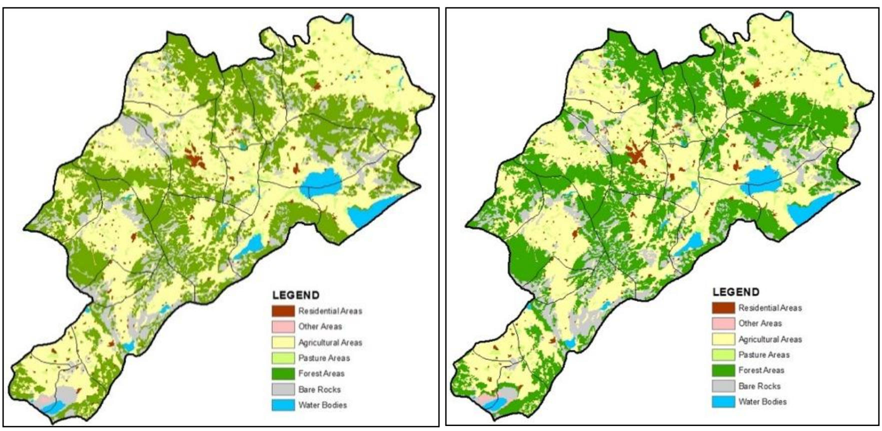

Figure 3. Land Use in 2000 and 2006.

Figure 4 shows the land use maps created for the years 2006-2012. During this six-year period, the most significant increase occurred primarily in agricultural areas, totaling 1,833 ha. The next most significant increase was observed in residential areas (1,373 ha) and bare rocky areas (1,166 ha). Along with these, the significant decrease in pasture areas (5,218 ha) is also noteworthy.

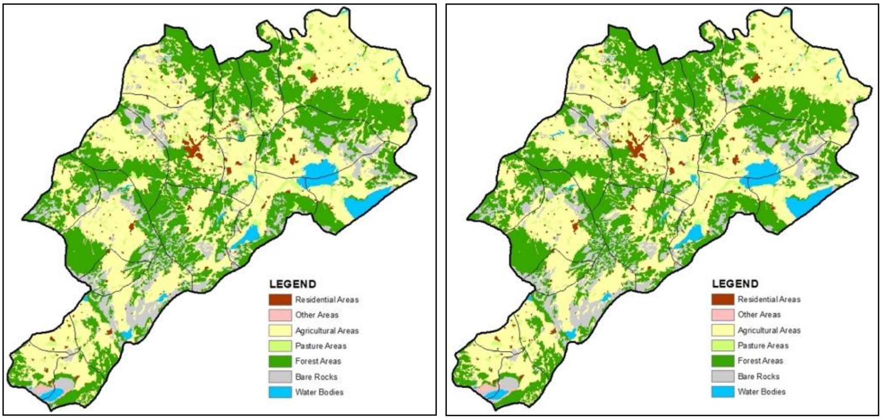

Figure 4. Land Use in 2006 and 2012.

Figure 5 shows land use maps created for the years 2012-2018. During this six-year period, there was an increase of 685 ha in residential areas. Along with this, there was a decrease of 689 ha in forest areas.

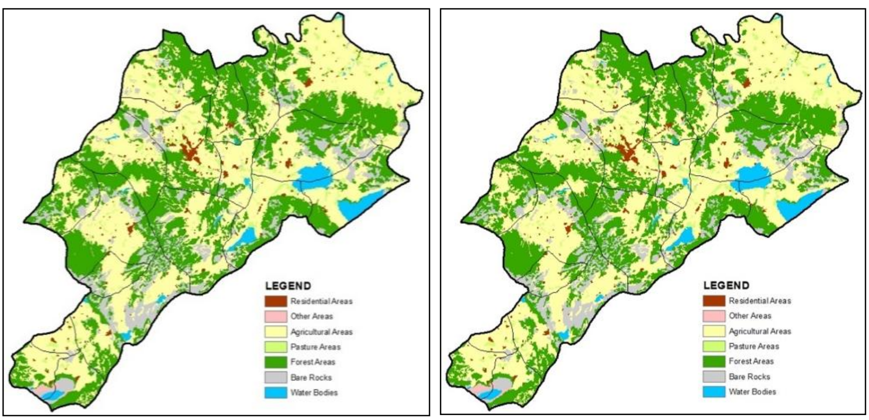

Figure 5. Land Use in 2012 and 2018.

4. Conclusion and Suggestions

This study examines changes in land use classes in Afyonkarahisar Province between 1990, 2000, 2006, 2012, and 2018 based on CORINE data. Over the 28-year period, the areas of residential areas, agricultural areas, forest areas, and water bodies increased, while the areas of pasturelands, bare rocky areas, and other areas decreased (Table 3, Figure 6). The largest increase among land classes was 16,545 ha in forest areas, while the largest decrease was 25,479 ha in bare rock areas.

Table 3. Changes in Land Use in Afyonkarahisar Province Between 1990 and 2018.

	Residential Areas (ha)	**Agricultural Areas (ha)**	**Forest Areas (ha)**	**Pasture Areas (ha)**	**Bare Rocks (ha)**	**Water Bodies (ha)**	**Other Areas (ha)**
1990-2000	5,482	4,644	16,545	-1,052	-25,479	8,949	-9,817

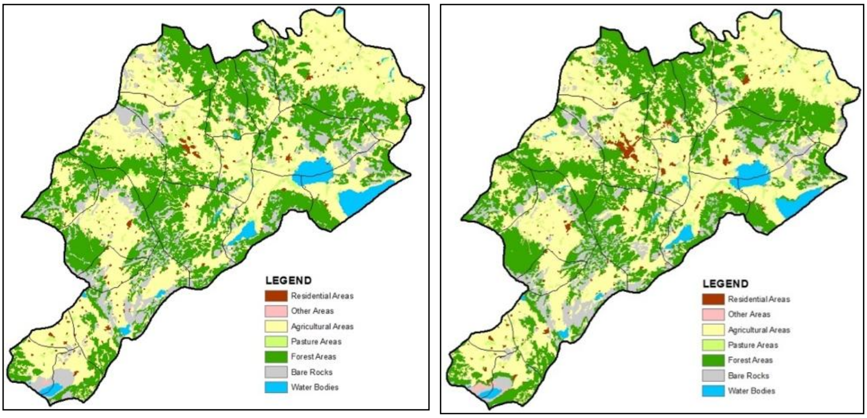

Figure 6. Land Use in 1990 and 2018.

This study, which aims to evaluate environmental and spatial transformations in Afyonkarahisar province by revealing land use changes that occurred between 1990 and 2018, shows that significant changes in land cover have occurred due to the combined effects of human activities and natural processes. During the period under review, an increase of approximately 16,545 ha was observed in forest areas, which can be interpreted as an indication of both afforestation activities and natural regeneration processes. Similarly, the 8,949 ha increase in water surfaces can be attributed to dams, reservoirs, or water management policies. However, significant decreases were observed, particularly in bare rock areas (25,478 ha) and other areas (9,816 ha). These decreases can largely be explained by the conversion of these areas into agricultural, forest, or water areas. A decrease of 1,051 ha in pasture areas was also observed; this may be related to the decline in livestock farming activities or the exposure of these areas to agricultural and settlement pressures. Another notable finding in land use is the increase in settlement areas (5,482 ha) and agricultural areas (4,643 ha). This increase can be explained by dynamics such as the spread of rural and urban settlements, population growth, and the expansion of agricultural production areas. This trend indicates that land use pressure in the region is increasing, which is a concern from the perspective of sustainable land management.

When evaluated overall, it was determined that productive areas such as forests, agricultural lands, and settlements increased significantly during the period analyzed in the study area, while natural and semi-natural areas (especially bare rock, pastures, and other areas) decreased. This situation indicates that land use decisions in the region may pose a risk to environmental sustainability in the long term. It is assessed that land allocations made without considering topographic, ecological, and soil characteristics may lead to both the destruction of natural resources and the weakening of ecosystem services. In this context, the findings presented for Afyonkarahisar province highlight the necessity of developing comprehensive planning approaches based on sustainable land use principles. It is of critical importance that land use policies are shaped not only by economic development goals but also by strategies that take ecological balance into account in order to prevent environmental degradation and protect natural resources.

Acknowledgements and Information Note

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Author Contributions and Conflict of Interest Declaration

This book chapter was written by a single author, and there are no conflicts of interest to declare.

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Horizontal Structure Techniques in 3D Concrete Printed Buildings

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1. Introduction

The concept of production using three-dimensional (3D) printers emerged around the mid-20th century and has since been applied across various disciplines. The integration of this technology into the construction sector dates back to the 1980s. Initially, this method—based on the additive manufacturing principle of stacking layers to fabricate either load-bearing or non-load-bearing components—relied on a limited range of materials. Over time, however, advancements in the technology have enabled the use of a broader spectrum of materials (Bos, Wolfs, Ahmed & Salet, 2016).

One of the materials that can be effectively utilized and is continuously evolving in the context of 3D printing is concrete. Three-Dimensional Concrete Printing (3DCP) technology has gained significant momentum in the 21st century, increasingly being employed in more complex applications. As material technologies advance, production capabilities expand, and practical experience accumulates, 3DCP is anticipated to become an even more integral component of the construction industry in the near future. The historical development of 3DCP can be summarized as follows (Bos et al., 2016; Buswell, De Silva, Jones, & Dirrenberger, 2018; Lyu, Zhao, Hou, Sun, & Zhang, 2021):

- Three-Dimensional Concrete Printing (3DCP) was first conceptualized in 1997 by Joseph Pegna at Rensselaer Polytechnic Institute in New York, where its feasibility was initially explored.

- In 1998, Behrokh Khoshnevis and his team at the University of Southern California developed a concrete printing technique known as Contour Crafting (CC). This method is based on the layer-by-layer extrusion of a concrete mixture through a computer-controlled printing apparatus to form the outer contours of concrete structural elements. The cavities created by these contours can either be filled with concrete or left hollow, depending on the production approach. During the printing process, each layer is simultaneously leveled on both horizontal and vertical surfaces. In the CC method, a high-quality surface finish and geometric precision are achieved through the use of an integrated trowel system, consisting of top and side trowels, mounted on the printhead (Figure 1) (Khoshnevis, 2004).

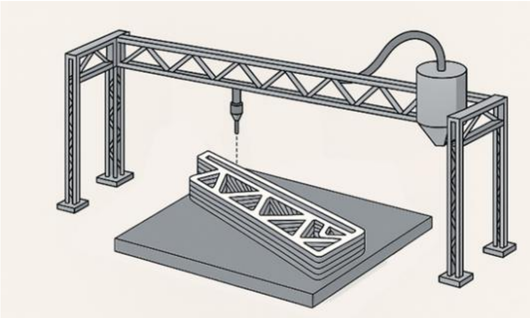

Figure 1. Illustration of the Contour Crafting Method (Created by the Authors).

- The D-Shape method was developed in 2006 by civil engineer Enrico Dini. In this technique, a binding material is sprayed onto a powder bed composed of sand and lime through multiple nozzles. The nozzles are typically mounted on a rigid portal system. The D-Shape method is particularly suitable for producing large-scale structural components with non-standard, free-form geometries (Figure 2) (Lyu et al., 2021; Tu et al., 2023).

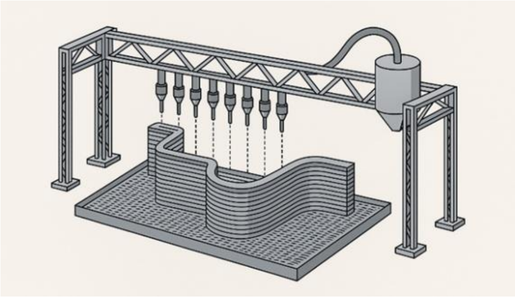

Figure 2. Illustration of the D-Shape Method (Created by the Authors).

- In 2009, a research group led by Buswell, Le, and Lim at Loughborough University developed the Concrete Printing method. In this technique, a specially formulated concrete mixture is deposited layer by layer to construct a structure. The concrete exhibits characteristics of self-compacting and sprayed concrete, gaining strength without the need for vibration or formwork. As the material adheres to the underlying layer under its own weight, it allows for the incorporation of reinforcement, utility conduits, and similar channels within the printed elements. This method is anticipated to enable the construction of structures of various scales and functions in the future (Figure 3) (Lim et al., 2011; Genç, 2019; Lyu et al., 2021).

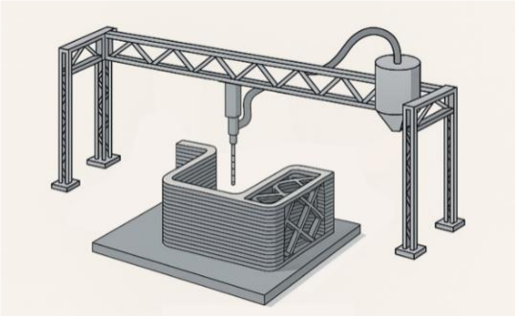

Figure 3. Illustration of the Concrete Printing Method (Created by the Authors).

- In 2012, the Mesh Mould project was launched at ETH Zurich for the fabrication of concrete structural elements with complex geometries. This project involves the full-scale (1:1) production of non-linear concrete load-bearing components without formwork, utilizing robotic fabrication methods (Figure 4) (Lyu et al., 2021; URL-1).

Figure 4. Visuals from the Mesh Mould Project (URL-1).

- In 2014, the company Winsun in China successfully 3D-printed the walls of ten houses in less than 24 hours. In the same year, a castle was constructed in the United States using concrete printing technology (Figure 5) (Feng & Yuhong, 2014; Hossain, Zhumabekova, Paul, & Kim, 2020).

Figure 5. Winsun's Production and the Castle Structure in the United States (Feng & Yuhong, 2014; Hossain et al., 2020).

- In 2015, the company Winsun constructed a five-story apartment building using three-dimensional concrete printing machines. The structure, produced with a 40 × 10 × 6.6 m printer, represents the first multi-story building constructed through concrete printing. In the same year, the company also produced a 1,100 m² residential building using concrete printing technology (Figure 6) (Çerçevik, Toklu, Kandemir, & Yaylı, 2018; URL 2).

Figure 6. Structures Produced by Winsun (URL-2).

- In 2016, Winsun constructed a 250 m² office building in Dubai, with concrete-printed components produced over 17 days and assembled on-site in just two days. This building became the world's first office structure manufactured using concrete printing technology (Figure 7) (Hossain et al., 2020; Pawar, 2024).

Figure 7. The Office of the Future in Dubai (URL-3).

- In 2017, the world's first bridge constructed using three-dimensional concrete printing was completed. Located in Gemert, the Netherlands, this bicycle bridge was produced in collaboration with BAM Infra and the Technological University of Eindhoven (TU/e), measuring 8 meters in length and 3.5 meters in width. Shortly after, additional 3D-printed bridges were built, including a 26.3-meter bridge in Shanghai, China, and a 29-meter bridge in Nijmegen, the Netherlands. These structures are significant as they demonstrate the applicability of 3D printing technology for engineering and infrastructure projects (Figure 8) (Miri, Baaj, & Polak, 2025).

Figure 8. Three-dimensional Concrete Printed Bridges Located in Gemert, Shanghai, and Nijmegen (URL-4, 5).

- In 2017, the company Apis-Cor produced a 37 m² residential unit in Moscow, Russia, within 24 hours. This residence represents the first building to be entirely printed on-site. With this project, the potential of robots to perform on-site construction was demonstrated to the world (Figure 9) (Sakin & Kiroglu, 2017).

Figure 9. Residential Unit Produced by Apis-Cor (Sakin & Kiroglu, 2017).

- In 2017, the Yhnova Project was constructed in Nantes, France, using the BatiPrint3D technique. The building was completed on-site in 54 hours. In this method, 3D printing machines produce foam-based formworks, which are subsequently filled with concrete to complete the structure. The significance of this project lies in it being the first 3D-printed concrete building officially designated for residential occupancy by a family (Figure 10) (Poullain, Paquet, Garnier, & Furet, 2018).

Figure 10. Visuals from the Yhnova Project (Poullain et al., 2018).

- In 2019, the company Apis Cor constructed a two-story public building in Dubai. The structure measures 9.5 meters in height and has a floor area of 640 m². At the time, it was recognized as the largest 3D-printed concrete building in the world and is considered a milestone in the production of large-scale structures using concrete printing technology (Figure 11) (Puzatova, Shakor, Laghi & Dmitrieva, 2023).

Figure 11. The Dubai Municipality, Largest 3D-Printed Construction (URL-6).

- Since 2020, the construction of buildings using three-dimensional concrete printers has commenced across many countries in Europe and around the world.

Construction with three-dimensional concrete printing (3DCP) is a building method with the potential to transform the construction industry, offering several advantages over traditional techniques. The primary advantages include:

- Economic advantages (Xiao et al., 2021; Kul, 2024):
    - Labor costs are significantly reduced,
    - Formwork costs are eliminated,
    - Material costs can decrease depending on the composition used (e.g., the use of recycled aggregate materials),
    - Material storage and transportation expenses are minimized in the case of on-site printing,
    - Overall project costs are reduced due to shortened construction times.
- Time efficiency (Al-Tamimi Alqamish, Khaldoune, Alhaidary & Shirvanimoghaddam, 2023; Kul, 2024):
    - Construction time is reduced by approximately 50–70% compared to traditional methods, significantly accelerating building processes,
    - The method greatly enhances efficiency in the fabrication and construction of complex designs and non-linear geometric structures.

- Design flexibility and innovations (Kuzmenko, 2021; Xiao et al., 2021):
    - 3DCP technology enables the construction of free-form geometries without the need for formwork, offering greater freedom in architectural design,
    - The method allows for customized production without requiring the fabrication of standardized elements.
- Sustainability (Xiao et al., 2021; Shahzad, Umair, & Waqar, 2022):
    - 3DCP projects are executed with detailed preliminary studies and precise planning. The required material quantities are meticulously calculated, minimizing material waste,
    - The absence of formwork eliminates formwork waste,
    - Reduced energy consumption during production lowers carbon emissions throughout the construction process,
    - The technology supports the use of recycled materials, contributing to sustainable construction practices.
- Technical and safety advantages (Xiao et al., 2021; Anton, Skevaki, Bischof, Reiter & Dillenburger, 2022; Miri et al., 2025):
    - Software-controlled printing ensures a high degree of accuracy in material placement,
    - Human errors and geometric deviations are minimized,
    - Continuous monitoring of the production process through sensors ensures compliance with quality standards,
    - Increased mechanization in the production process significantly reduces injuries and accidents on construction sites.

Despite these significant advantages, it is essential to note that the industrial application of 3D concrete printing (3DCP) is still in its infancy and that several aspects require further development. These aspects can be addressed under structural, economic, and practical implementation categories. Among the primary structural limitations is the challenge of printing horizontal load-bearing elements using 3D concrete printers.

This study aims to evaluate the current state, technical limitations, and application-scale deficiencies of 3DCP technology in the production of horizontal load-bearing structural components through a literature-based approach. Despite advancements in the printing of vertical load-bearing elements, the production of horizontal components such as slabs and beams continues to face considerable challenges, including rheological constraints, interlayer adhesion issues, deficiencies in reinforcement integration, and problems with geometric stability. Within this scope, existing 3D concrete printing applications are examined to highlight how these structural limitations, primarily associated with horizontal load-bearing systems, affect the integration of this technology into innovative urbanization models involving multi-story and complex architectural structures.

2. Production Techniques for Horizontal Structures

While effective methods and techniques have been developed for the production of vertical components (e.g., walls, columns) and shell or enclosed forms (e.g., domes, arches), the fabrication of horizontal elements (e.g., slabs, beams) has not yet achieved significant success. This limitation primarily stems from the inability of the freshly printed concrete to support its own weight and the underdeveloped integration of reinforcement into the printed material. Currently, this area remains in its infancy, and numerous experimental and theoretical studies are being conducted to address the associated challenges.

Within the scope of this study, solutions developed for the horizontal load-bearing elements of 3D concrete-printed (3DCP) structures were examined through analyses of existing applications. In this context, the production techniques were categorized into four main approaches. The classifications identified for horizontal element production in 3DCP are as follows (Figure 12):

a. Direct Layered Extrusion (DLE)
b. Formwork-Supported Printing (FSP)
c. Hybrid Construction Systems (HCS)
d. Modular Fabrication Techniques (MFT)

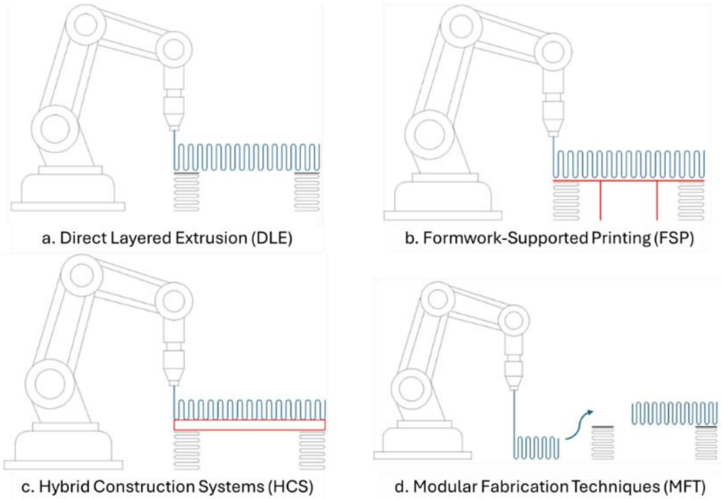

Figure 12. Illustration of Horizontal Structure Production Techniques in 3DCP (Created by the Authors).

2.1. Direct Layered Extrusion

The Direct Layered Extrusion (DLE) method is based on the technique of depositing concrete material in successive layers through a 3DCP machine without the use of formwork or temporary supports. This method is widely applied for printing vertical elements; however, it presents technical challenges in directly printing horizontal load-bearing components without any support or formwork. The primary issue arises from the inability of freshly extruded concrete to sustain its own weight until it gains sufficient strength, leading to sagging or deformation along the span (Breseghello & Naboni, 2022).

Currently, research and development efforts are ongoing to enable the production of horizontal elements using the Direct Layered Extrusion (DLE) method. The main focus areas and representative examples of these studies are as follows:

- Kazemian et al. (2017) focused on enhancing concrete properties by incorporating additional reinforcements such as fibers and fly ash into the mix, aiming to improve the material from various aspects and achieve high-performance concrete,
- Breseghello and Naboni (2022) aimed to reduce material usage and enhance strength by optimizing the printing pattern.

Although DLE method has enabled geometric solutions through the printing of arches or domes, the production of horizontal load-bearing elements using this method has not yet reached full technological maturity. Nevertheless, ongoing studies offer promising prospects that this method will evolve and enable the integrated production of structures through 3DCP.

2.2. Formwork-Supported Printing

This method utilizes temporary support elements or formworks to assist the 3D printing process, thereby enabling the production of horizontal planar forms. The primary objective is to prevent the deformation of fresh concrete layers during printing and to ensure that these layers maintain the desired geometric shape until sufficient strength is achieved. Various techniques exist for providing temporary support, including the use of conventional formworks, sand embedding, sacrificial/melting molds (e.g., 3D-printed polymer molds), or formworks printed with concrete material. The utilization of printed formwork as a supporting element represents a significant sub-approach. In this method, the load-bearing component itself is not directly printed; instead, a thin-walled formwork that defines the internal cavity of the element is produced via additive manufacturing, after which the cavity is filled using conventional concrete casting techniques. The printed formwork may either remain in place as a permanent component of the structure or be removed once the concrete has sufficiently hardened. This approach constitutes an effective solution that combines the free-form capabilities offered by 3D printing with the structural robustness of conventional reinforced concrete (Breseghello & Naboni, 2022).

A study conducted by Maitenaz et al. (2020) demonstrated that this method can be effectively applied to reinforced concrete beams designed in compliance with Eurocode 2 standards. In their research, a formwork with variable-depth cavities along the longitudinal section of the beam was produced using a 3D printer. After positioning the reinforcement within the printed mold, the cavity was filled with concrete to complete the structure. This approach enabled the precise fabrication of complex internal void geometries, and the resulting beam exhibited performance characteristics comparable to those of conventional reinforced concrete elements (Figure 13) (Maitenaz, Mesnil, Onfroy, Metge & Caron, 2020).

Figure 13. Beam Fabricated by Maitenaz et al. (2020).

Granular medium support represents an alternative approach within this method. In this technique, a medium composed of sand or lightweight aggregate is employed to support the fresh concrete during the printing process, preventing deformation under its own weight. Kim (2024) successfully fabricated a horizontal frame-structural component using the Granular Medium Concrete Printing method. The granular medium served as a bedding layer for the beam segments, allowing the fabrication process to proceed without the influence of gravity-induced deflection. Using sand-supported printing, a small-scale column–beam–slab system was produced as a demonstration. The study highlighted that this approach enables the additive manufacturing of frame structures with complex geometries (Figure 14) (Kim, 2024).

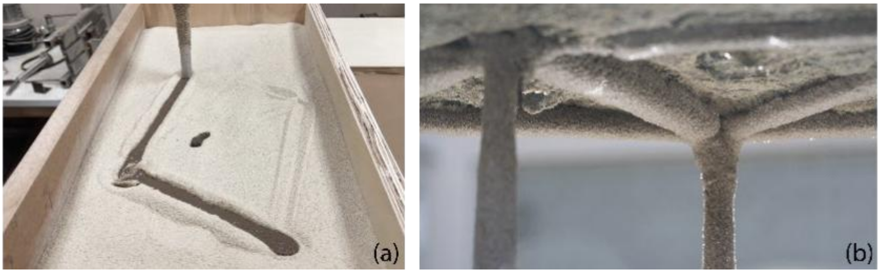

Figure 14. Visuals from the Study Conducted by Kim (2024).

A further 3D printing method utilizing temporary formwork involves the use of scaffolding. In this approach, sand beds or wooden/steel support beams and plates are positioned beneath the horizontal spans of the project, providing provisional support for the printing process. Once the concrete achieves the desired strength, these supports are removed, allowing the layer-by-layer fabrication process to continue seamlessly (Figure 15).

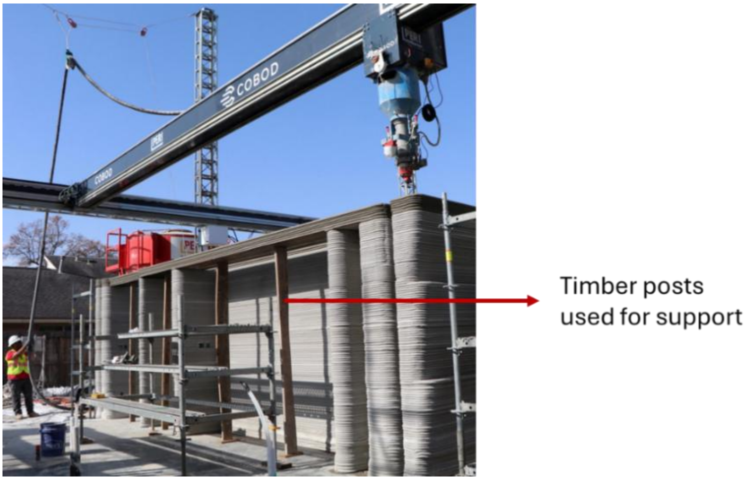

Figure 15. Example of Scaffold-Formwork Utilization in 3DCP Construction (URL-7).

In formwork-supported 3D printing methods, the formwork elements directly affect both the material properties and the structural performance of the printed components. When the printed formwork is intended to remain as a permanent part of the structure, the printing material must exhibit sufficient mechanical strength and provide adequate adhesion and compatibility with other construction materials. A noteworthy example of this approach is the Yhnova House in France, which employed the Batiprint3D technique. In this project, two thin foam-based formwork walls were 3D printed, and the space between them was filled with conventional concrete to complete the structure. The printed walls functioned as permanent formwork, becoming an integral component of the building’s structural system. (Figure 16).

Figure 16. Visuals from the Batiprint3D Method (URL-8).

The temporary formwork-supported method, while limiting the form flexibility of 3D printing, represents a significant approach that facilitates the production of horizontal elements. In this method, horizontal spans that cannot be directly printed are fabricated by incorporating conventional techniques alongside the 3D printing process. However, the integration of traditional construction methods necessitates additional labor and materials, thereby hindering full automation.

2.3. Hybrid Construction Systems

Hybrid systems represent construction solutions that integrate both 3D Concrete Printing (3DCP) technology and advanced conventional construction materials and methods. This approach aims to combine the advantages of both domains: the formwork-free production and free-form design capabilities of 3D printing are synergized with the structural strength and other benefits of traditional and prefabricated systems. Hybrid methods are particularly significant for the production of horizontal load-bearing elements, as they offer effective solutions to critical challenges such as reinforcement integration and load transfer.

The hybrid approach involves the combined use of both prefabricated and additively manufactured components. As an illustrative example, Domenico Asprone et al. (2018) developed a composite beam system by integrating 3D-printed segments with steel reinforcement. In this system, each segment featuring a complex geometry was produced through a layered additive manufacturing process, after which the components were assembled using post-tensioned steel cables. This method effectively combines the geometric flexibility of 3D printing with the high tensile strength of steel (Figure 17) (Asprone, Auricchio, Menna & Mercuri, 2018).

Figure 17. Visuals from the Study by Asprone et al. (2018).

The hybrid method for producing horizontal elements also includes the technique of printing concrete onto semi-prefabricated components. These semi-prefabricated elements can range from thin concrete slabs to preassembled reinforcement cages. A notable example of this approach is the Mesh Mould project developed at ETH Zurich. While this research primarily focuses on vertical walls using robotically fabricated steel meshes, advanced applications suggest its potential adaptation for horizontal load-bearing elements as well (Figure 18) (URL-1).

Figure 18. Visuals from the Mesh Mould Project (URL-1).

The Minimass Beam Project, designed and developed by NetZero Projects (NZPs), represents a significant example of hybrid fabrication methods. In this project, the 3D-printed concrete beam is structurally integrated with a post-tensioned steel element placed beneath it. Compared to a conventional reinforced concrete beam, the Minimass beam achieves a 70% reduction in reinforcement and a 76% reduction in concrete usage (Figure 19) (Coward & Sørensen, 2023; URL-9).

Figure 19. Minimass Beam Project (URL-9).

The primary advantage of hybrid systems lies in their ability to integrate the design freedom offered by 3D printing with the structural reliability of conventional construction methods. However, hybrid systems also present certain drawbacks, including challenges in achieving full automation and the necessity of multiple production stages. The connection details between printed and traditionally manufactured components must be carefully designed to prevent potential issues such as cold joint formation. Current research emphasizes that without hybrid approaches, the applicability of 3D concrete printing technology in the construction of multi-story and complex structures will remain considerably limited.

2.4. Modular Fabrication Techniques

The modular fabrication approach involves subdividing structural systems into smaller components, each of which is produced using 3D printing and subsequently assembled on-site to form the complete structure. This strategy is particularly effective for structures requiring long spans and high load-bearing capacity. Large-scale elements that are difficult or impossible to fabricate under on-site conditions can be produced in a controlled factory environment as separate modules and then assembled in situ. The primary motivation for employing this method is to overcome limitations imposed by printer dimensions and gravity-induced constraints.

Notable examples of modular fabrication in engineering structures include the 29-meter-span bicycle bridge in Nijmegen and the bridge designed by Zaha Hadid Architects. The components of these bridges were prefabricated using 3D concrete printing and subsequently assembled on-site. Figure 20 illustrates these bridges along with their respective fabrication and assembly processes.

Figure 20. Top Row: 3DCP Bridge Produced by Zaha Hadid Architects; Bottom Row: Bicycle Bridge Located in Nijmegen (URL-10, 11).

The modular production method is widely employed in architectural structures produced using 3D concrete printing. Notable examples include The Office of the Future in Dubai and the five-story apartment buildings constructed in China by Winsun. Figure 21 illustrates these structures along with their production processes.

Figure 21. Top Row: The Office of the Future; Bottom Row: Five-Story Apartment Building (Matarneh & El-Ashri, 2018; URL-12).

One of the fundamental challenges of modular 3D printing, similar to the prefabrication process, lies in the design of joint details. Specialized solutions such as epoxy adhesives, metal connectors, or post-tensioning cables may be required between produced elements, which increases design complexity and labor time. Additionally, each module must conform to transport constraints regarding size and weight, making post-production logistics and assembly planning critically important.

Despite these challenges, the modular approach remains one of the most preferred strategies in practice because it mitigates uncertainties associated with on-site conditions and transfers production to controlled factory environments, enabling climate-independent quality control. Currently, many 3D printing companies (e.g., COBOD, WinSun) favor the strategy of producing components such as wall panels, columns, or beam modules off-site and assembling them in situ, rather than printing the entire structure directly on-site. This approach is regarded as a provisional model until on-site printing technologies reach full maturity.

3. Findings and Discussion

In this section, four primary methodologies employed in three-dimensional concrete printing (3DCP) for building production—Direct Layered Extrusion (DLE), Formwork-Supported Printing (FSP), Hybrid Construction Systems (HCS), and Modular Fabrication Techniques (MFT)—are comparatively analyzed within the framework of various technical and practical criteria. Each system is evaluated under critical parameters such as structural performance, constructability, cost efficiency, technological complexity, design flexibility, and scalability. The purpose of this analysis is to identify the strengths and limitations of different production approaches, thereby supporting more rational design and implementation decisions tailored to the specific requirements of the field.

From the perspective of structural performance, the Direct Layered Extrusion (DLE) method is inherently limited due to the challenges associated with the integration of tensile reinforcement and the inability to print large horizontal spans without support. In particular, for horizontal load-bearing elements such as slabs and beams, the structural capacity achieved through this approach remains insufficient compared to conventional methods. The Formwork-Supported Printing (FSP) method enhances load-bearing capacity by securely supporting the layers through the use of temporary formwork and facilitates the incorporation of tensile reinforcement. This approach demonstrates a high degree of compatibility with conventional structural standards. Hybrid Construction Systems (HCS), through the combined use of semi-prefabricated components and 3D printing technology, deliver superior mechanical performance, providing an effective alternative particularly for long-span slab solutions. Conversely, Modular Fabrication Techniques (MFT) enable the production of high-strength, code-compliant solutions by manufacturing prefabricated slab units—often reinforced or post-tensioned—within controlled workshop or factory environments.

From a constructability standpoint, the Direct Layered Extrusion (DLE) method offers the advantage of requiring minimal on-site setup; however, it presents significant technical challenges in the unsupported printing of horizontal elements. This necessitates advanced rheological optimization and inherently limits the feasibility of large-span applications. The Formwork-Supported Printing (FSP) method, while extending production time due to the need for formwork installation and additional labor, enables the safe and controlled fabrication of horizontal structural elements. Hybrid Construction Systems (HCS) demand a high level of organizational and integrative capacity, as they require the precise coordination of multiple systems during the construction process. Modular Fabrication Techniques (MFT), by leveraging controlled factory conditions, offer substantial quality control benefits; nonetheless, the transportation and placement of large prefabricated components can present logistical challenges, particularly under site-specific constraints.

From a cost-effectiveness perspective, the Direct Layered Extrusion (DLE) method can offer material savings due to its formwork-free production; however, this advantage is largely offset by material waste and increased labor costs resulting from trial-and-error processes, particularly in the fabrication of horizontal elements. Additionally, supplementary reinforcement may be required to compensate for structural deficiencies.

Formwork-Supported Printing (FSP), although initially appearing more expensive due to formwork requirements, reduces failure rates during production and thereby maintains an overall balanced cost. The potential for reusing formwork further enhances its cost efficiency. Hybrid Construction Systems (HCS) incur higher upfront costs due to the need for advanced coordination and specialized expertise in both design and production; however, the superior performance and flexibility achieved can rationalize these expenditures over the long term. In the case of Modular Fabrication Techniques (MFT), initial investments in formwork and assembly are offset by the speed and repeatability afforded by serial production. Conversely, in highly customized production scenarios, costs can rise substantially.

From the perspective of technological complexity, the Direct Layered Extrusion (DLE) method demands highly precise machine calibration and advanced control systems, making production quality particularly sensitive to environmental factors. In Formwork-Supported Printing (FSP), the level of technological complexity varies depending on the type and configuration of the formwork system employed. Hybrid Construction Systems (HCS) are inherently complex, as they require the seamless coordination of multiple production components and processes. Modular Fabrication Techniques (MFT), on the other hand, necessitate advanced technical infrastructure in terms of automation, assembly systems, and formwork preparation, thereby imposing a high technological demand on the overall production process.

From a design flexibility perspective, Direct Layered Extrusion (DLE) offers architects a high degree of freedom for creating complex geometries and voided slab systems. However, this potential is not fully realized in practice due to current production limitations and technical constraints. In Formwork-Supported Printing (FSP), formwork requirements inherently restrict geometric freedom, though these constraints can be partially mitigated through computer-aided formwork technologies. Hybrid Construction Systems (HCS) provide limited yet controlled design flexibility, as they rely on the configuration of semi-prefabricated components. Modular Fabrication Techniques (MFT), in turn, shape design flexibility largely around assembly, transportability, and production hardware, resulting in a degree of freedom that varies significantly depending on the project context.

From the perspective of scalability and practical application, Direct Layered Extrusion (DLE) is suitable for small-scale production but remains largely experimental for horizontal load-bearing elements requiring wide spans. Formwork-Supported Printing (FSP) is primarily adopted for prototype fabrication and research-oriented projects, as the setup and installation of formwork are time-intensive. Hybrid Construction Systems (HCS) are generally applied in high-level or large-scale projects, where the need for coordination increases proportionally with building size. Modular Fabrication Techniques (MFT), by contrast, are widely implemented in bridges, residential complexes, and institutional buildings due to their advantages in serial production, transportability, and ease of on-site assembly—demonstrating the method's viability for industrial-scale applications.

A concise summary of the conducted analysis is presented in Table 1.

Table 1. Summary of the Analysis of Horizontal Structure Production Methods in 3DCP.

Criteria / Methods	DLE	FSP	HCS	MFT
Structural Performance	Weak	High	High	Superior
Constructability	Complex	Conventional	Complex	Organizational
Cost-Effectiveness	Variable	Efficient	Efficient	Variable
Technological Complexity	Advanced	Moderate	Advanced	Variable
Design Flexibility	High	Limited	Limited	High
Scalability	Small	Medium	Large	Large
Application	Experimental	Common	Common	Common

4. Conclusion and Recommendations

This study provides a comprehensive evaluation of the current state, technical limitations, and practical scalability of 3D Concrete Printing (3DCP) technology for the production of horizontal load-bearing structural elements. The primary objective of this research is to critically analyze the challenges associated with implementing 3DCP in horizontal structural components, elucidate the strengths and weaknesses of existing methodologies, and thereby establish a foundational assessment to inform and guide future applications.

Within the scope of this study, four primary methods for the fabrication of horizontal load-bearing elements—Direct Layered Extrusion (DLE), Formwork-Supported Printing (FSP), Hybrid Construction Systems (HCS), and Modular Fabrication Techniques (MFT)—were thoroughly examined and comparatively assessed. The technical advantages and limitations of each approach were systematically identified and critically evaluated.

The evaluation revealed that the integration of Three-Dimensional Concrete Printing (3DCP) technology into innovative and multi-story urban development projects remains in its developmental stage, primarily due to fundamental technical limitations in the fabrication of horizontal structural elements. In particular, deficiencies in reinforcement integration, inadequate interlayer adhesion, and uncertainties related to geometric stability emerge as critical constraints that currently hinder the reliable production of structural components such as slabs and beams. These findings indicate that, while 3DCP has so far been applied mainly in experimental prototypes and small-scale projects, its industrial-scale adoption requires comprehensive research efforts and multifaceted technological advancements.

In terms of future research priorities, the development of innovative reinforcement integration techniques should be considered a primary necessity. Hybrid reinforcement strategies, post-tensioning systems, and fiber-reinforced composites represent key approaches to enhance the tensile performance of horizontal spans. In parallel, rheological optimization of printable concrete mixtures remains critical to ensure both early-age load-bearing capacity and long-term durability. Furthermore, to support the transition from laboratory-scale studies to real-life applications, pilot projects involving modular and hybrid systems should be implemented in collaboration with the construction industry. Such projects are expected to validate the feasibility and scalability of these methods under practical conditions, thereby accelerating the maturity of the technology.

Beyond technical advances, the widespread adoption of 3DCP also depends on the establishment of regulations and standardization frameworks. Defining performance criteria, quality control protocols, and safety standards tailored to this technology will not only expedite industrial adaptation but also promote sustainable construction practices by encouraging the use of recycled aggregates and environmentally friendly binders. Finally, research focusing on the integration of digital design tools and robotic manufacturing systems will further enhance automation, efficiency, and architectural flexibility, thereby positioning 3DCP as a transformative construction method in the realization of innovative and resilient urban environments.

Collectively, these recommendations provide a comprehensive and interdisciplinary roadmap for advancing 3DCP from an experimental approach into a sustainable, reliable, and industrially applicable method of construction in the near future.

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Solution Proposals for Reducing Carbon Footprint with Smart City Approaches

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1. Introduction

The climate crisis has emerged as a profound global challenge that threatens both the environmental sustainability of cities and human well-being. At the core of this challenge lies the carbon footprint, a key indicator that quantifies the greenhouse gas emissions generated by urban production and consumption patterns. Urbanization, positioned simultaneously as a driver and a consequence of climate change, creates a complex two-way interaction that reshapes ecological and socio-economic systems (Kołsut & Kudłak, 2023). Empirical evidence demonstrates that cities are responsible for a substantial share of the global carbon footprint while also representing the most vulnerable settlements to the adverse effects of climate change (Das et al., 2024). Manifestations such as sea-level rise, particularly in coastal metropolitan areas, amplify risks to critical infrastructure and urban living environments. Consequently, the intricate nexus between climate change and urbanization has evolved into a strategic priority within contemporary sustainability policies (Founda, Katavoutas, Pierros & Mihalopoulos, 2022).

The concept of carbon footprinting provides a critical tool for analyzing the environmental impacts of cities. A carbon footprint represents the total amount of greenhouse gases released into the atmosphere by individuals, communities, or cities over a specified period (Vihma & Hukkinen, 2024). This measurement provides insight into current environmental impacts and enables the development of effective carbon reduction strategies. Factors such as transportation, energy consumption, construction, and land use constitute the primary components of urban carbon emissions (Güloğlu, Erkan & Çimen, 2023).

The transportation sector, in particular, is the largest source of emissions in many large cities, primarily due to heavy vehicle traffic and fossil fuel consumption (Kumaş, Akyüz & Güngör, 2019). Similarly, energy consumption in terms of functions such as heating, cooling, and lighting has a direct impact on the carbon performance of cities (Seyhan & Çerçi, 2022). Furthermore, the decrease in green spaces and the increase in artificial surfaces during urbanization disrupt the natural carbon cycle, leading to higher emission rates (Binboğa & Ünal, 2018). Therefore, reducing the carbon footprint is a priority that must be addressed at the city level to achieve sustainable development goals (Pourzolfaghar, Bastidas & Helfert, 2019; Zjalic et al., 2023).

In this context, smart city approaches provide a holistic and innovative strategy with the potential to reduce the environmental impacts of urban areas. A smart city can be broadly defined as an urban settlement that integrates information and communication technologies (ICT) with sustainable planning practices to improve the efficiency of services, reduce resource consumption, and enhance the quality of life for its residents (Ahvenniemi, Huovila, Pinto-Seppä & Airaksinen, 2017). Goals such as increasing energy efficiency, optimizing resource and waste management, improving mobility through intelligent transportation systems, and integrating green space planning with digital technologies constitute the fundamental pillars of this approach (Prasetyo & Habibie 2022). By linking technological innovation with sustainability objectives, it becomes possible to monitor and reduce the urban carbon footprint, thereby improving cities' overall climate performance.

The discipline of landscape architecture is one of the fundamental fields supporting the integration of nature and technology in smart cities. Natural components integrated with smart infrastructures enable cities to become both more resilient and more livable (Kalkan, Tekeli & Coşkun, 2025). Landscape architecture offers multifaceted contributions to this process, including not only spatial aesthetics but also ecological functionality, the creation of carbon sinks, and microclimate regulation (Verlinghieri, Brovarone & Staricco, 2023). Furthermore, climate-sensitive landscape designs have become a strategic tool in combating climate change, supporting both life and the conservation of natural resources through the maintenance of ecosystem services (Russell & Christie, 2021).

This study aims to evaluate the impact of smart city approaches on reducing carbon footprints from a landscape architecture perspective, to propose holistic solutions within the scope of sustainable urban planning, and to highlight the role of this discipline in environmental management strategies. In this context, national and international examples of smart strategies implemented in cities are comparatively examined, and the potential contribution of these approaches to environmental sustainability is assessed. The contribution and strategic role of landscape architecture in carbon reduction and smart city planning are emphasized by synthesizing the existing literature. The scope of the study is to analyze the success of integrating digitalization and nature-based solutions by evaluating projects implemented at the urban scale. Methodologically, current studies in national and international literature are reviewed, and based on these findings, landscape-focused strategic recommendations for city management are developed (Rice, Cohen, Long & Jurjevich, 2019;

Murgante & Annunziata, 2025). Thus, the chapter provides a multidimensional and innovative assessment of how smart city designs that integrate nature and technology can be implemented within the framework of landscape architecture, while also guiding future research and interdisciplinary applications.

2. Conceptual and Spatial Foundations of Smart Cities: A Carbon-Focused Approach

Developed in response to the environmental, economic, and social challenges facing cities today, smart city approaches integrate technology, data analytics (data-based analysis processes), and sustainability principles in a holistic approach. These strategies make cities more livable, resilient, and environmentally friendly, while also making significant contributions to reducing carbon emissions (Bibri & Krogstie, 2020).

The solutions proposed for reducing carbon footprints, which this study focuses on, are addressed based on the conceptual and spatial components of smart city approaches. These components aim to enhance environmental performance at various scales, ranging from the digitalization of urban systems to the implementation of green infrastructure. In this context, the key components that stand out in the carbon-focused transformation of smart cities are:

2.1. Smart Infrastructure Systems

Smart infrastructure systems, a cornerstone of smart city approaches, play a strategic role in reducing cities' carbon footprints. Because key infrastructure components such as energy, transportation, and water management are directly linked to greenhouse gas emissions, innovative solutions developed in these systems offer significant contributions to urban sustainability (Lahmouri, Drewes & Gondhalekar, 2019).

In the field of energy management, smart energy systems facilitate the integration of renewable resources and increase system efficiency by regulating energy demand in a data-driven manner (Fan & Wei, 2022). Smart grids, microgeneration systems, and energy storage technologies reduce dependence on fossil fuel use and lower carbon emissions. Landscape architecture contributes to the spatial sustainability of energy infrastructure through designs such as passive energy strategies, shading elements, and microclimate adjustments in open spaces.

In transportation systems, smart technologies reduce carbon emissions through applications such as infrastructure that monitors and directs traffic density, electric vehicle charging stations, and the integration of public transportation (Tarek, 2023). These solutions not only reduce emissions but also make urban mobility healthier, more accessible, and more environmentally friendly. In this context, landscape architects directly contribute to this transformation through spatial applications such as the design of green transportation corridors and the integration of bicycle and pedestrian paths.

Water management is another component of sustainable infrastructure design. Smart water systems minimize water losses and support the cyclical use of resources through technologies such as rainwater harvesting, smart meters, and leak detection (Nieto & Espitaleta, 2021; Wang et al., 2022). These systems strengthen cities' water resilience, particularly in response to the increasing risk of drought caused by climate change. Landscape architecture contributes to this area through nature-based strategies, including permeable surfaces, biofiltration systems, rain gardens, and natural drainage solutions (Kalkan & Coşkun, 2025). Therefore, smart infrastructure systems should be considered not only as tools for technological transformation, but also as sustainability elements that strengthen cities' environmental performance and require interdisciplinary interaction. Shen et al. (2022) emphasize that basing infrastructure on data-driven analysis is decisive in developing effective policies to reduce carbon emissions. At this point, landscape architecture plays an active role in urban infrastructure planning, not only in terms of spatial dimensions but also in ecological and social aspects.

2.2. Digital Technologies

Digital technologies, as one of the fundamental building blocks of smart cities, enable urban management to become more agile, data-driven, and sustainable. In particular, the Internet of Things (IoT) and data analytics systems collect real-time data through sensors integrated into city infrastructures, thereby improving the quality of decision-making in administrative processes (Noori, Jong, Janssen, Schraven, & Hoppe, 2020).

IoT technologies enhance system efficiency in areas such as transportation, energy, waste, and water management by enabling simultaneous data flow between city components, thereby contributing to the more efficient use of resources (Almalki et al., 2021). The application areas of these systems on smart city components and their impact on carbon emissions are summarized in Table 1.

Table 1. The Effects of Digital Technology Applications on Carbon Footprint.

Digital Technology	Application Area	Contribution to Carbon Reduction	Reference
IoT sensors	Water management	Monitoring water leaks, preventing waste	Wang et al., 2022
Smart meters	Energy efficiency	Monitoring consumption, reducing unnecessary use	Buuse & Kolk, 2019
Data analytics systems	Transportation optimization	Preventing traffic congestion, reducing fuel consumption	Noori et al., 2020
Decision support systems	Landscape planning	Preservation of green spaces, monitoring of ecological services	Fan & Wei, 2022

Analyzing this data facilitates the development of policies tailored to the unique needs of cities, paving the way for local-scale solutions (Chang et al., 2023). This data-driven approach not only improves governance processes but also strengthens environmental sustainability. Digital strategies developed to achieve key objectives, such as increasing energy efficiency, reducing carbon emissions, and meeting decarbonization targets, have a positive impact on the environmental aspects of smart city planning (Buuse & Kolk, 2019). It is worth noting that Fan & Wei (2022) suggest that green space protection and land management practices should also be integrated into this process, as this integration plays a significant role in carbon reduction. Therefore, digital technologies should not only be considered tools that optimize urban functioning; they should also be viewed as strategic components that enhance environmental resilience and work in conjunction with landscape planning processes.

2.3. Green Infrastructure and Nature-Based Solutions

Green infrastructure is a sustainable planning approach that provides multifunctional ecosystem services by integrating natural and semi-natural elements into urban systems. These systems, which increase the environmental resilience of cities, contribute to reducing carbon emissions, mitigating the heat island effect, and improving air quality through structures such as green roofs, urban forests, parks, and permeable surfaces (Romanelli, 2021; Prasetyo & Habibie, 2022). They also pave the way for the creation of cities resilient to climate change through functions such as supporting biodiversity, rainwater management, and regulating urban microclimates (Topsakal & Sağlık, 2024).

Green roof systems and afforestation projects reduce cities' carbon emissions by creating natural carbon sinks, while permeable surface applications contribute to the natural water cycle (Xu et al., 2024). These practices offer not only environmental but also social benefits; public green spaces, in particular, support the physical and psychological well-being of city residents (Civan & Görmüş, 2023). Tayouga & Gagné (2016) state that an interdisciplinary approach is essential for green infrastructure to become functional. The successful implementation of nature-based planning and spatial strategies is made possible through the guiding role of disciplines such as landscape architecture. At this point, green infrastructure should be considered not only a component of physical design but also a cornerstone of a highly climate-sensitive urban planning approach (Selim, 2021).

Green corridors, a key component of urban green infrastructure, protect biodiversity by establishing ecological connections between different habitats and reduce motor vehicle use by increasing walkability (Sicard, Agathokleous, Marco, Paoletti & Calatayud, 2021; Stipanović et al., 2022). The ecosystem services provided by these corridors in rapidly developing cities are also supported by research (Cui, Ferreira, Fung & Matos, 2021).

Vertical green systems implemented in densely populated areas transform building facades into carbon sinks, thereby reducing energy consumption and enhancing urban aesthetics (Li et al., 2022). These practices enhance energy efficiency by regulating the interaction between the building envelope and the surrounding microclimate. Similarly, urban forests and extensive afforestation projects play a key role in helping cities achieve carbon neutrality. These areas not only serve as carbon sinks but also provide multifaceted benefits such as improving air quality, providing recreational space, and strengthening the ecological integrity of the landscape (Baró et al., 2014; Nor, Corstanje, Harris, Grafius & Siriwardena, 2017).

Nature-based solutions have a wide range of impacts. They offer numerous benefits, including rainwater management, thermal regulation, carbon sequestration, and improved air quality. Protecting and increasing green spaces within cities not only reduces emissions but also directly contributes to social dimensions such as environmental justice and quality of life (Webster & Leleux, 2018).

The combined and holistic implementation of all these strategies enhances the sustainability performance of cities and clearly demonstrates the crucial role landscape architecture plays in combating climate change. Therefore, green infrastructure applications are among the fundamental approaches that support the environmental performance of smart cities and embody the integration of nature and technology.

2.4. Low-Carbon Transportation Scenarios and the Role of Landscape Architecture

Landscape architecture plays a central role in creating the spatial infrastructure necessary to promote low-carbon modes of transportation. Spatial planning decisions aimed at mitigating the environmental impacts of transportation both reduce carbon emissions and enhance the quality of sustainable urban life. Low-carbon transportation scenarios are shaped by holistic approaches based on bicycle-focused design, pedestrian-first planning, and accessibility principles (Tarhan & Ercoşkun, 2023). This section will discuss how these three fundamental strategies can be evaluated within the context of landscape architecture.

2.4.1. Bicycle-focused design

Bicycle-focused transportation is a key building block of sustainable cities. This subheading examines the impact of bicycle infrastructure on carbon emissions and its connection to landscape architecture. Expanding bicycle paths reduces reliance on motor vehicles for urban transportation and lowers carbon emissions. This approach offers both environmental and economic benefits, while also promoting the adoption of a healthy and active lifestyle. Cabiroğlu & Özden (2022) emphasize that extending bicycle paths increases bicycle use, providing a safe, economical, and environmentally friendly transportation alternative. Integrating bicycle paths with green corridors creates a safe and sustainable transportation infrastructure, thus increasing environmental benefits.

2.4.2. Pedestrian-friendly design principles

Pedestrian-friendly urban design directly supports sustainability and accessibility goals. This section examines the environmental impacts of walkability and its connection to the quality of public spaces. Pedestrian-friendly design principles are an effective way to promote environmentally friendly modes of transportation in urban areas. Safe, accessible, and comfortable walking paths allow individuals to move more freely within the city as pedestrians while indirectly reducing motor vehicle use (Tapağ & Suri, 2023). In this context, accessibility planning not only ensures ease of transportation but also ensures equal access to space for different age and ability groups. Özkaraca & İnceoğlu (2021) state that safety, social participation, and accessibility should be considered fundamental principles in such design processes.

2.4.3. Holistic transportation planning

Integrated planning of all transportation components is crucial for the success of low-carbon city goals. This section illustrates the role of synchronization between transportation systems in reducing carbon emissions. The success of low-carbon transportation scenarios is possible through the integration of bicycle paths, walking networks, public transportation systems, and high-speed rail lines. A transportation infrastructure that integrates these systems effectively increases social solidarity and consistently and measurably reduces carbon emissions. Tarhan & Ercoşkun (2023) demonstrated that a park-and-ride system in Istanbul reduces motor vehicle use by encouraging people to use public transportation, significantly reducing air pollution and carbon emissions.

Integrating landscape architecture with low-carbon transportation strategies is a fundamental step in building sustainable cities. Bicycle-centric design and a pedestrian-first approach not only reduce environmental impacts but also strengthen social interaction and improve quality of life. Chen et al. (2022) emphasize the need to increase infrastructure investments for cycling, while Yang et al. (2023) state that accessibility planning has the potential to address individual needs while simultaneously reducing carbon emissions. Therefore, making transportation systems more inclusive, accessible, and environmentally impactful is directly aligned with the carbon footprint reduction goals of smart cities.

2.5. Energy-Efficient Open Space Design

Energy efficiency is a critical sustainability goal that can be directly impacted not only at the building level but also through the design of urban open spaces. The climatic characteristics of open spaces reduce energy consumption by reducing the need for artificial air conditioning through microclimate adjustments. Microclimate adjustments should be implemented by considering environmental parameters such as wind direction, sunshine duration, shading potential, and natural airflow (Lin et al., 2023). By considering these elements, landscape architects develop designs that both increase user comfort and reduce structural energy requirements.

2.5.1. Shading strategies

Shading is a crucial component of open space design and is achieved through the combined use of natural (trees, vines) and artificial (pergolas, awnings, sunshades) elements. Shaded areas prevent overheating and provide coolness in open spaces (Tırnakçı, 2021). Shading strategies reduce heat stress during the summer months and are effective in maintaining thermal balance by limiting the heat island effect within the city (Binboğa & Ünal, 2018). Such strategies minimize negative environmental impacts and reduce users' energy costs (Ingemarsdotter, 2021).

2.5.2. Permeable soil applications

Permeable soil applications are an important element that indirectly contributes to energy efficiency. These applications enable rainwater to be controlled as it passes through the ground and filtered into underground systems, thereby lowering surface temperatures and reducing the risk of flooding (Köse, Oktay, Gündeş & Durmaz, 2022). Permeable soil systems ensure sustainable rainwater management and contribute to energy efficiency by supporting evaporation and evapotranspiration processes (Shafiquzzaman, 2021).

2.5.3. Planting and microclimate adjustments

Planting strategies are also critical for energy efficiency. Selecting plant species suited to the local climate reduces irrigation needs, thereby indirectly contributing to energy savings (Carpentier et al., 2012). Proper vegetation arrangements help manage summer temperatures by creating shading and cooling effects (Lin et al., 2023). Furthermore, microclimate adjustments are a crucial part of the landscape design process, enhancing the environmental comfort of open spaces while also improving energy savings.

2.5.4. Relationship with building energy performance

Energy efficiency is important not only in the design of open spaces but also in the building envelope and environmental integrity associated with these spaces. The permeable surfaces, vegetative cover, and reflective materials used by landscape architects in their projects enhance building energy performance, contributing to energy savings and user comfort (Kırbaş & Kocakulak, 2022).

In this context, energy-efficient open space design is a strategic planning area that, along with aesthetics and user experience, serves to reduce carbon emissions. The integration of shading, permeable surfaces, and planting strategies enhances both environmental sustainability and quality of life (Perini, Ottelé, Haas & Raiteri, 2012). Therefore, landscape architecture practices should be considered in terms of energy efficiency and play an active role in combating climate change.

2.6. Interdisciplinary Perspective in Ecological Urban Design

Ecological urban design necessitates an interdisciplinary approach to achieving sustainable urbanism goals. Fields such as architecture, urban and regional planning, and landscape architecture play complementary roles in ensuring environmental, social, and economic sustainability (Ersoy, 2017). This collaboration not only enhances the quality of spatial design but also enables the achievement of multifaceted goals such as reducing carbon emissions, efficient use of natural resources, and developing user-centered living spaces (Wu et al., 2023).

Luan et al. (2021) emphasize that interdisciplinary integration, in addition to physical features such as aesthetics and functionality, also promotes social sustainability. Othman (2019) demonstrates that adopting holistic planning models in natural resource management not only minimizes environmental impacts but also makes cities more resilient to the climate crisis. In this respect, interdisciplinary collaborations in the ecological city design process are considered not only a method but also a strategic necessity.

Smart city approaches developed in line with this understanding combine numerous components, from infrastructure systems and digital technologies to green infrastructure applications and nature-based solutions, enabling the reduction of carbon footprints and the making of cities more livable. Thus, an urban planning model based on ecological and technological partnerships offers tangible contributions to the vision of a sustainable city of the future.

3. International and Turkish Examples of Smart City Strategies for Carbon Reduction

Smart city strategies aimed at reducing carbon footprints are being implemented with varying priorities in different geographies and are shaped by each country's social, economic, and environmental conditions. In this regard, examples from both leading international countries and cities, as well as Türkiye, offer various approaches to environmental sustainability in smart city planning. Table 2 below summarizes the strategic practices of some leading cities.

Table 2. Comparative Analysis of Smart City Strategies for Carbon Reduction with International and Turkish Examples (Created by the Author).

City	Application Area	Strategies and Implementations
Copenhagen	Carbon-Neutral Transport and Urban Form	Bicycle-oriented transportation, energy-efficient buildings, green roofs, open data for public awareness
Amsterdam	Digital Twin and Compact Urban Development	Urban planning with digital data, digital twin simulations, nature-based urbanism, citizen participation
Singapore	Integrated Water and Green Infrastructure Systems	Smart water management, vertical forests, biophilic design, green building certifications
Konya	Transport and Open Space Planning	Bicycle master plan, green corridors, transport integration, climate-responsive urban open spaces
Eskişehir	Green Space and Urban Aesthetic Management	Data-supported landscape planning, ecological parks, sustainable recreational areas
Istanbul	Urban Transformation and Digital Infrastructure	Smart transportation systems, energy-efficient building retrofitting, disaster-focused digital planning platforms

This comparative framework demonstrates how cities are developing diverse yet effective strategies to achieve their carbon emission reduction targets. For example, integrating bicycle infrastructure into urban planning in Copenhagen has significantly reduced carbon emissions from transportation. However, some projects, such as "Copenhill," have produced results that contradict carbon neutrality goals, raising questions about the city's environmental vision (Kohl & Andersen, 2022).

Amsterdam has set targets to reduce greenhouse gas emissions by 55% by 2030 and 95% by 2050, compared to 1990 levels, and has taken significant steps toward achieving these targets through digital twin modeling (Lam & Hoek, 2020).

Singapore, on the other hand, has developed integrated solutions that ensure environmental sustainability in a tropical megacity through vertical green systems and biophilic urban design. Vertical gardens and green building practices enhance both urban aesthetics and carbon sink capacity, thus contributing to the improvement of the urban microclimate (Oral et al., 2021). Furthermore, these practices encompass not only the physical environment but also social aspects such as water management, public health, and environmental awareness (Mendes & Pina, 2023).

While examples in Türkiye are shaped more regionally, Konya's bicycle network-focused planning and green corridor system demonstrate a sustainable transportation vision similar to the Amsterdam model (Adıyaman, Özçalık & Doygun, 2022). Buildings and roads that encourage cycling are designed to improve the city's transportation infrastructure; within this framework, it is emphasized that the overall transportation network should include not only motor vehicles but also alternative modes such as bicycles (Demircan & Başgün, 2023). While Eskişehir's green space continuity and aesthetic quality evoke landscape integration in European cities, Istanbul, with its digital infrastructure and disaster-focused planning, draws a practice profile similar to Singapore's (Gerdan & Şen, 2020). Istanbul, in particular, aims to increase citizen safety through digital solutions in disaster management (Başkaya, 2023).

These comparative examples demonstrate that smart city strategies encompass not only technical but also spatial and socio-ecological dimensions. Landscape architecture stands out as one of the disciplines that bridges these components and integrates sustainability into physical space (Cömertler & Cömertler, 2021). The development of nature-based solutions, the planning of green infrastructures, and the integration of carbon sinks are directly related to the expertise of landscape architects (Karaca & Özkan Önem, 2023). These contributions also increase the resilience of cities against the climate crisis and align spatial planning processes with environmental objectives (Elitaş & Sönmez, 2022). Therefore, the more effective inclusion of a landscape architecture perspective in local governments' smart city strategies is a critical step in achieving environmental sustainability goals (Karslı, Yılmaztürk, Bahadır, Özdemir & Karslı, 2022). In the future, it is anticipated that landscape-based practices aimed at enhancing ecosystem services, as well as urban planning and digital infrastructure, will be further encouraged (Düzleme & Demircan, 2024).

Overall, cities like Copenhagen, Amsterdam, and Singapore are implementing comprehensive, multilayered strategies toward carbon neutrality by integrating nature-based solutions, digital technologies, and community engagement mechanisms (Gür & Kahraman, 2022). These cities not only reduce carbon emissions but also enhance the quality of life and establish healthy, resilient urban structures, serving as global models (Şengül & Sarıkaya, 2023). This framework, informed by international experience, can contribute to further strengthening urban planning practices in Türkiye, aligning them with nature-based and interdisciplinary strategies.

4. Findings and Discussion

The findings discussed in this section demonstrate that policies aimed at reducing carbon footprints should be supported not only by advanced technologies but also by nature-based strategies and spatial planning approaches. The search for solutions to reduce carbon emissions takes shape at the intersection of various urban components, including energy systems, transportation, water management, open space design, and digital infrastructure. Therefore, comparing the themes discussed with current literature offers a holistic perspective on how environmental sustainability can be enhanced in smart city planning.

In the context of smart infrastructure systems, the role of digital solutions used in key sectors such as energy and water management in reducing carbon emissions is consistent with studies such as Lahmouri et al. (2019) and Wang et al. (2022). In particular, the efficient use of renewable energy resources through smart grids stands out as a critical mechanism for cities to achieve their carbon neutrality goals. This approach has been successfully implemented in exemplary cities such as Amsterdam and Singapore (Oral et al., 2021).

The integration of digital technologies into urban management has a direct impact on carbon reduction. Noori et al. (2020) emphasizes that IoT-based data systems increase resource efficiency by reducing waste in water and energy use. These technological advances also enable decision-making processes to become more agile and responsive to local dynamics. The use of decision support systems in green space planning proposed by Fan & Wei (2022) provides a concrete example of the sustainable management of carbon sinks.

Nature-based solutions and green infrastructure practices play an important role as passive strategies that reduce carbon emissions. Romanelli (2021) and Topsakal & Sağlık (2024) state that green roof systems and permeable surfaces are effective in reducing the urban heat island effect and increasing carbon sequestration. Modifying urban microclimates and reducing urban energy demand through natural shading strategies are important contributions also emphasized by Tırnakçı (2021) and Binboğa & Ünal (2018). These findings are consistent with the successes achieved with vertical forest applications in Singapore (Oral et al., 2021).

Bicycle-focused and pedestrian-first design approaches, specifically for transportation, not only reduce carbon emissions but also support social sustainability. Cabiroğlu & Özden (2022) and Tarhan & Ercoşkun (2023) have demonstrated that these systems provide both environmental and social benefits by reducing motor vehicle use. Park-and-ride systems in Istanbul and bicycle integration practices in Konya are local practices that overlap with this literature (Demircan & Başgün, 2023).

International examples shed light on the multilayered nature of smart city strategies. Copenhagen and Amsterdam have set carbon-neutral targets by integrating both digital and nature-based planning, while Singapore has improved its environmental performance through biophilic designs within high-density developments (Kohl & Andersen, 2022; Mendes & Pina, 2023). The common denominator of these cities is their implementation of strategies that simultaneously evaluate community participation and environmental data.

Exemplary practices from cities like Eskişehir, Konya, and Istanbul in Tükiye offer a range of tools, from green infrastructure to digital planning; however, these strategies continue to require support from holistic, long-term plans. The role of local governments in this transformation extends beyond the implementation of projects to the development of data-driven monitoring and evaluation systems (Karslı et al., 2022; Düzleme & Demircan, 2024). Overall, smart city approaches to reducing carbon footprints offer multifaceted solutions that strengthen cities' environmental resilience, enhance local government capacity, and integrate spatial planning with sustainability principles. Literature findings and international/national examples demonstrate that this transformation requires not only technical but also social, administrative, and ecological dimensions to be addressed together.

5. Conclusion and Suggestions

Smart city approaches offer a strategic framework that should be considered in conjunction with the discipline of landscape architecture in developing solutions to reduce carbon footprints. This study analyzed this potential at a thematic level and developed solutions within the context of nature-based, digitalized urban strategies. In this context, interdisciplinary, nature-based, and technology-focused solutions were proposed through thematic sections. The findings reveal that for cities to achieve environmental sustainability, they must be supported not only by technological infrastructure but also by landscape-based strategies such as green infrastructure, microclimate modifications, permeable surfaces, and carbon-conscious planning.

The goal of reducing the carbon footprint is possible not only through the digitalization of energy systems but also by redesigning the urban fabric based on ecological resilience. Therefore, smart cities must be redesigned with an approach that integrates nature and technology. Landscape architecture is at the center of this process, playing a critical role in both planning nature-based solutions and ensuring the continuity of ecosystem services in public spaces.

This study reveals how multidimensional landscape strategies, such as green infrastructure practices, low-carbon transportation models, and energy-efficient open space design, are becoming increasingly visible in the future of cities. Comparative assessments supported by international and national examples demonstrate that these strategies contribute to both environmental and social sustainability.

Recommendations for future academic studies include:

• Supporting landscape-based carbon reduction scenarios in smart cities with spatial modeling.

• Studies on the traceability of green infrastructure performance with digital data systems.

• Compiling successful practices incorporating landscape architecture into smart city planning processes and integrating them into the literature.

• Evaluating nature-based solutions within the framework of social inclusion and climate justice.

• In-depth analysis of interdisciplinary interactions within the context of governance models.

Ultimately, the future of cities must be shaped by a vision of an urban environment that is not only "smart" but also "harmonious with nature." This vision necessitates an approach that integrates technology with environmental sustainability, aligns spatial planning with ecosystem services, and centers interdisciplinary knowledge production. Landscape architecture, as both a strategic and implementing actor in this new generation of urban design, will assume a more decisive role in the coming period.

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This book chapter was written by a single author, and there are no conflicts of interest to declare.

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Management of Historic Rural Landscapes within the Framework of Permaculture-Oriented Sustainable Conservation Approaches

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1. Introduction

Historic rural landscapes are complex systems shaped by the long-term and continuous interactions between humans and nature, where social, cultural, economic, and ecological relations are spatially manifested (Antrop, 2005; Çoban, 2012). These areas encompass not only physical structures bearing witness to the past but also traditional knowledge systems, local modes of production, communal memory, and sustainable relationships with natural resources (Gür, 2020). As landscapes that embody both tangible and intangible components of cultural heritage, they serve as carriers of social identity, supporters of ecological balance, and foundations of local sustainability. The conservation of historic rural landscapes is a multi-layered process that involves social, cultural, economic, and ecological dimensions beyond the mere protection of the physical environment. Such landscapes represent dynamic systems resulting from the interaction between nature and culture, integrating both tangible and intangible elements of cultural heritage (Taylor & Lennon, 2011; Antrop, 2005).

At the international level, institutions such as UNESCO and ICOMOS recognize cultural landscapes as the shared heritage of humanity. UNESCO's 1992 definition of cultural landscapes, adopted under the World Heritage List, describes these areas as "geographical areas that have cultural value as a result of the long and complex interactions between people and nature" (UNESCO, 1992). This definition categorizes cultural landscapes into three main types:

1. Designed landscapes: Areas consciously created or designed by humans.

2. Organically evolved landscapes: Areas formed primarily due to social, economic, administrative, and/or religious necessities, shaped by their relationship with and response to the natural environment; further divided into ‘relict’ and ‘continuing’ landscapes.
3. Associative landscapes: Areas included in the World Heritage List for their strong religious, cultural, or artistic associations with natural elements, where tangible cultural evidence may be minimal or absent.

ICOMOS regards the conservation of cultural landscapes as an indispensable tool for ensuring cultural continuity and the maintenance of community identities (ICOMOS, 2017). These definitions emphasize that landscapes should be understood not solely as natural or cultural entities but as dynamic systems in which these two components coexist.

However, historic rural landscapes today face multidimensional threats. Impacts of climate change, water scarcity, soil degradation, industrialization of agricultural production, rural-to-urban migration, aging rural populations, spatial pressures, and tourism-driven transformations lead to disruptions in the natural, cultural, and socio-economic structures of these unique areas (Pedroli et al., 2007; Keleş & Hamamcı, 2005). Similar processes in Turkey, particularly in small-scale and dispersed rural settlements, threaten traditional ways of life and the integrity of cultural landscapes (Asatekin, 2004; Erdoğdu, 2015).

Conventional conservation approaches tend to focus predominantly on architectural and monumental assets, often neglecting the ecological cycles, production systems, and community-based relationships inherent in the landscape (Taylor & Lennon, 2011). Yet, cultural landscapes are not merely objects to be preserved but living systems. Therefore, redefining conservation necessitates a holistic approach that acknowledges the protection of not only physical assets but also the natural and social systems that sustain them (Plieninger & Bieling, 2012).

At this juncture, permaculture—offering nature-compatible design systems aligned with sustainability principles—provides an alternative and innovative framework for cultural landscape conservation. Permaculture is grounded in energy and resource efficiency, cyclical systems, multifunctional spatial organization, and local knowledge systems (Mollison, 1988; Holmgren, 2002). This design approach addresses not only agricultural production but also water management, settlement patterns, social organization, and networks of solidarity, thereby contributing comprehensively to the continuity of cultural landscapes in rural areas (Ferguson & Lovell, 2014; Çüçen, 2011).

This book chapter will explore both theoretical and applied aspects of managing historic rural landscapes based on permaculture-oriented sustainable conservation approaches. Initially, the concept of cultural landscapes and relevant national and international conservation frameworks will be evaluated. Subsequently, spatial planning, ecological restoration, local community participation, and governance models will be discussed within the context of permaculture principles. The aim is to move beyond physical interventions in cultural landscape conservation, redefining and integrating the relationships among nature, culture, and society in accordance with sustainability principles to propose a comprehensive conservation approach.

2. Material and Method

In this study, a theoretical framework was developed in accordance with qualitative research traditions. This chapter, which does not rely on empirical fieldwork, is based on the systematic review, conceptual analysis, and interpretation of relevant literature.

Methodologically, national and international academic sources, reports, theoretical approaches, and normative documents (such as those by ICOMOS, UNESCO, and the European Landscape Convention) focusing on cultural landscapes, sustainable conservation, permaculture principles, rural heritage, and climate sensitivity were examined.

An interdisciplinary approach was adopted within this theoretical foundation. Conceptual insights were drawn from various fields including landscape architecture, conservation, environmental policy, and cultural heritage studies to analyze the strengths and weaknesses of existing conservation approaches in a theoretical context. Additionally, the applicability of the permaculture approach to historic rural landscapes was discussed within the framework of sustainability and ecological design principles.

The study employs a descriptive and analytical method, focusing on the usage, definitions, and transformations of selected concepts in the literature, aiming to elucidate the relationships among these concepts and their impacts on conservation practices.

3. Historic Rural Landscapes and Approaches Developed for Their Conservation

Traditional conservation approaches have primarily prioritized the protection of tangible cultural heritage, focusing largely on material cultural elements such as buildings, monuments, and works of art. Following World War II, conservation gained an international dimension, accompanied by increased attention toward rural areas. Parallel to this development, growing awareness led conservation practice to evolve beyond the scale of individual buildings, adopting a more comprehensive approach aimed at preserving urban fabric and intangible cultural heritage. The designation of qualified natural areas as “natural sites” and their protection was another significant advancement of this period. Nonetheless, the conservation of landscapes where natural and cultural values coexist—landscapes emerging from this interaction—now represents one of the prominent contemporary conservation paradigms. Within this framework, the concepts of “cultural landscape” and “historic rural landscape” form the foundation of conservation approaches that have recently emerged in Turkey, integrating ecological sustainability principles in a holistic manner.

Historic rural landscapes, reflecting the interaction and shared life between humans and nature, can be categorized into three components: built environment, agricultural environment, and natural environment.

Built Environment: The built environment, developed according to human needs and comprising various building types, includes historic structures reflecting traditional construction systems, the fabric they create, and other buildings gradually integrated into this fabric. These areas demonstrate diverse developmental processes shaped by landform, topography, climatic conditions, agricultural activities, and other economic resources. Settlement characteristics shaped by land-use patterns and carrying traces of traditional rural life are molded according to the geographic features of their regions. Rural architectural examples constituting these fabrics are directly linked to local needs and functionality, embodying a traditional architectural understanding. Traditional settlements and buildings, which are fundamental components of historic rural landscapes, are constructed using local natural materials and indigenous building techniques, reflecting the cultural identity, social individuality, and uniqueness of their locale. Rural settlements characterized by a lifestyle founded on tradition vary “from region to region, even from village to village within the same region” (Eminağaoğlu & Çevik, 2007). These traditional settlements, established in rural areas, are conceived as integrated wholes with the natural environment, agricultural environment, and other existing resources. Rural architectural examples forming traditional settlements encompass the immediate surroundings and all production-related activities. The relationship among houses particularly reflects the social activities and neighborhood relations of their users. Rural architectural structures are built by local users using locally sourced materials and are designed parallel to the lifestyle culture, with a focus on functional use. Rural houses constructed from wood, stone, brick, and earth are shaped according to local data, dependent on climate and geographic characteristics. Local traditions develop worldwide in diverse ecological and cultural contexts, yet these traditions are shaped by regional and local conditions. They involve natural resources found in a given area, which are seldom used without appropriate construction technologies and without selection and adaptation processes (Krier, 2006).

Agricultural Environment: Agriculture and animal husbandry, as fundamental components of historic rural landscapes, represent significant livelihoods for these areas. The delineation of agricultural lands within settlement theory is shaped by natural factors such as topography, availability of water resources, and soil quality. Areas with high water retention capacity, low slope, and relatively flat terrain are considered suitable for agricultural production, and proximity to settlement centers is preferred. Vegetation, developed in response to local geographical conditions and climate, is one of the most defining elements of historic rural landscapes. The natural vegetation formed according to climatic parameters such as precipitation and temperature reflects the characteristic climate of the region and bears local qualities. In addition, cultivated agricultural lands shaped by human activity are managed with local production methods, creating an agricultural landscape—a landscape form oriented toward production. This landscape develops in interaction with natural plants and tree species, and climate-appropriate selected crops serve both food supply and economic income functions. Sustaining agricultural production with regard to biological and ecological balance is crucial for sustainability. In this context, local vegetable and fruit production meets the consumption needs of local people and ensures economic continuity through sales. Furthermore, forests—with their unique flora, fauna, and water resources—are important components not only for environmental balance but also for the sustainability of rural life. Agricultural production areas range from small-scale kitchen gardens and vegetable plots within settlements to larger-scale fields outside settlements. These areas have provided the foundation for production forms that have persisted for centuries. In traditional settlements, various functional structures related to the processing, storage, and marketing of products have been constructed directly associated with agricultural production. These structures constitute important elements of rural spatial organization.

Depending on the local character of vegetation, animal husbandry activities have also diversified and localized according to climatic conditions. Poultry, small ruminants, and large livestock constitute the primary food sources of local communities. Additionally, commercialization of these products contributes directly to the rural economy. Livestock activities leave spatial traces within traditional settlements. While small ruminant and poultry farming are more common within settlements, animal shelters (barns) appear outside settlements as either permanent or seasonal-use structures.

Natural Environment: Unlike the agricultural environment, forest areas hold vital importance as living components of the historic rural landscape due to their unique plant and animal species and water resources. Ensuring ecosystem continuity and the sustainability of rural life necessitates the protection of these natural areas. Declaring such ecologically valuable and preservable areas as "Natural Protected Sites" involves controlling and limiting their use accordingly.

In Turkey, the concept of Natural Protected Site is defined under Article 3(a) of Law No. 2863 on the Protection of Cultural and Natural Assets as natural areas that are of extraordinary characteristics due to their rarity, belonging to geological periods, and located on the surface, underground, or underwater, requiring preservation. Within this framework, natural protected areas designated by the Ministry of Environment, Urbanization, and Climate Change are classified into three main categories based on protection levels:

Strictly Protected Sensitive Areas: Declared by the Council of Ministers, construction is completely prohibited in these areas, and only scientific research activities are permitted. These areas are under absolute protection to prevent any intervention in the natural balance.

Qualified Natural Protection Areas: While protecting natural values remains paramount in these areas, local populations are allowed to use existing resources in accordance with their traditional lifestyles. This ensures the continuity of rural production methods and local life practices compatible with nature.

Sustainable Protection and Controlled Use Areas: These areas form ecological and spatial integrity with the above protection zones but allow limited intensity activities. Low-density settlement, agriculture, and tourism activities compatible with natural and cultural values are permitted under certain conditions.

One of the key documents prepared for the conservation of historic rural landscapes is the 2017 text titled "Principles Concerning Rural Landscapes as Heritage" by the International Scientific Committee on Cultural Landscapes (ISCCL) of ICOMOS and the International Federation of Landscape Architects (IFLA). This document highlights the concept of rural landscapes as terrestrial or wetland areas formed by human–nature interaction where renewable natural resources such as food and raw materials are produced (ICOMOS & IFLA, 2017). Rural landscapes, as dynamic and living systems, encompass all rural areas created or evolving through traditional methods, techniques, accumulated knowledge, cultural habits, or changes in traditional production approaches (ICOMOS & IFLA, 2017). Rural landscape heritage is defined as the tangible and intangible heritage of rural areas, including their physical features (productive land itself, morphology, water, infrastructure, vegetation, settlements, rural buildings and centers, traditional architecture, transportation and trade networks, etc.) and broader cultural and environmental connections. The document emphasizes the significance of rural landscapes, which have been shaped over millennia, as representing critical aspects of human and environmental history, lifestyle, and heritage (ICOMOS & IFLA, 2017).

The document further stresses that increasing industrialization, urbanization, population growth, and climate change expose rural landscapes to loss, abandonment, or other radical transformations. The threats to rural landscapes are grouped into three interrelated categories: demographic and cultural changes, structural changes, and environmental changes (ICOMOS & IFLA, 2017). Demographic and cultural changes include population growth, urban development, developmental pressures, and the loss of traditional practices, techniques, local knowledge, and cultures. Structural changes refer to globalization, economic growth or decline, intensified agricultural practices and techniques, and the loss of grazing lands and domesticated local species diversity. Environmental changes encompass climate change, pollution, degradation affecting soil, vegetation, air quality, biodiversity, and agricultural biodiversity (Güler, 2019). Within the ICOMOS and IFLA recommendations, the article emphasizing that "agriculture, forestry, animal husbandry, fishing, aquaculture, natural resources, and other key resources are essential for future human adaptation and global human resilience" highlights the importance of holistic conservation approaches with an ecological perspective.

In 2021, ICOMOS published the "Cultural Heritage and Sustainable Development Goals: Policy Statement and Recommendations," which includes climate and cultural heritage-related guidance. Recommendations focus on utilizing cultural heritage to build resilience against climate change, especially by developing landscape-based and community-wide solutions, ensuring active participation of indigenous peoples and cultures in biodiversity, and promoting the use of local resources and resilient heritage-based techniques. The statement calls for integrating climate sensitivity assessments, adaptation, and mitigation measures at all levels of heritage management policies, plans, and projects. The principle "Use heritage to enhance community adaptive capacity and build resilience to climate change" opened the way for sustainable change based on cultural heritage and climate change.

The document "Cultural Landscapes: Conservation Challenges" identifies difficulties in the conservation of cultural landscapes over time, such as unsuccessful cooperation among countries, limited implementation of global strategies for balanced World Heritage lists, regional imbalances (with 70% of registered sites located in Europe), insufficient capacity to propose reliable cultural landscape sites, lack of resources and weak institutions for effective management, rapid socio-economic changes, and problems coping with tourism. These issues have led to challenges in maintaining traditional land uses that form cultural landscapes, as well as weak links between the cultural landscape concept and other identification systems in this field (UNESCO, 2003). It is noted that most cultural landscape areas are still evolving, and their management should guide these changes and ensure the conservation of key characteristics (UNESCO, 2003). Education and capacity building are highlighted as key factors for effective management and monitoring of cultural landscapes, with an emphasis on supporting new approaches in local government training courses. The interdisciplinary nature of such education, bringing together ecology, culture, sociology, economics, and related expertise, is stressed (UNESCO, 2003). The document also states that sustaining cultural landscapes requires not only supporting traditional practices but also adapting new sustainable technologies (UNESCO, 2003).

Another important international organization working on the conservation of agriculturally significant systems, areas, and landscapes is the Food and Agriculture Organization (FAO) of the United Nations. FAO emphasizes that agriculturally important areas and landscapes have been shaped and developed over many years under the influence of cultural practices on natural resources. These areas, based on local knowledge and experience, reflect humanity's evolution, experiences, and deep relationship with nature, underscoring their importance for conservation (Güler, 2018).

Within the framework of green transitions, the European Green Deal has set goals for climate resilience through coherent and stable transformation policies across multiple sectors and disciplines. The 2019 European Green Deal comprises core elements such as climate, energy, industry, environment, agriculture and food, transportation, and finance. The Green Deal for European Cultural Heritage focuses on principles learned from cultural heritage to make everyday practices climate-friendly. For example, the reuse culture, a core principle of cultural heritage conservation, is linked to contributing to the EU's climate targets for 2030 and 2050 (Gençer, 2022). As a contribution to sustainability, the cultural heritage-based lifestyle harmonious with nature, the development of nature-based solutions focusing on energy efficiency and renewable energy use within ecological design approaches, is emphasized. Protecting agricultural heritage within historic rural landscape areas and adding ecological practices to traditional farming methods will support food systems' preservation and continuity. In this context, it is possible to transfer ecological principles recommended for climate adaptation from traditional built environments. Ecological/sustainable/green architecture principles advocating resource, energy, and water efficiency, waste reduction, and a transformation process mindful of nature intersect with many aspects of traditional architectural approaches formed by millennia of experience but largely neglected, forgotten, or abandoned today (Eres & Güler, 2022).

In 2014, the project "VerSus (Lessons from Vernacular Heritage to Sustainable Architecture: From Local Heritage to Sustainable Architecture)," conducted especially in France, Spain, Italy, and Portugal, aimed to establish and investigate the relationship between sustainability and vernacular concepts. It researched uncovering the embedded heritage elements of local heritage and connecting them with more recent ecological approaches. The sustainability dimension of local heritage was evaluated in three groups: environmental, sociocultural, and socioeconomic. The environmental aspect addresses humanity's capacity to reduce or prevent negative environmental impacts. Sustainability principles include respect for nature, appropriate siting, reducing pollution and waste, improving health quality, and mitigating natural disaster effects. The sociocultural dimension focuses on the relationship between people and place, addressing belonging, identity, and community development. Its sustainability principles include protecting cultural landscapes, transmitting building cultures, fostering creativity, recognizing intangible values, and promoting social cohesion. The most quantitative, socioeconomic aspect traditionally considers financial and monetary values as key indicators. Its sustainability principles detail supporting locality, encouraging local activities, optimizing construction, extending building lifespans, and conserving resources (URL-1).

In this study, under the heading Traditional Heritage-Focused Sustainability Principles, two subheadings were created: “Adaptation to Environment and Climate” and “Supporting Local People, Improving Living Conditions, and Efficient Use of Resources.” The first group, directly related to physical environmental conditions and nature, includes protection of cultural landscapes, appropriate siting, adaptation to topography, integration with natural landscapes and vegetation, and building form, envelope, and spatial organization. The Convention does not limit landscapes to merely aesthetic or historic areas but recommends integrating landscapes, as living spaces for all people, holistically into planning and conservation processes (Council of Europe, 2000). Thus, it emphasizes the need to support conservation policies with principles such as ecological sustainability, participatory management, and empowerment of local communities.

4. The Concept and Components of Permaculture

In 1968, a group of thirty individuals—including scientists, educators, economists, industrialists, and public officials—convened to discuss the present and future condition of the world. Their aim was to promote understanding of the various but interconnected economic, political, natural, and social components that make up the global system. By raising awareness among policymakers and the public, they sought to inspire action. This group later became known as the Club of Rome, now an internationally recognized organization. Following this initial meeting, the Club of Rome published a report highlighting five key factors that determine—and ultimately limit—growth on the planet: population, agricultural production, natural resources, industrial production, and environmental pollution (Meadows, Meadows, Randers & Behrens, 1972). Emerging in response to the environmental awareness sparked by the 1972 Club of Rome report, permaculture was one of the alternative approaches proposed to address environmental concerns. A second wave of environmentalism, triggered by increasing public awareness of the greenhouse effect in the late 1980s, further accelerated interest in permaculture (Holmgren, 2002). First introduced through the work of Bill Mollison and David Holmgren in the mid-1970s, permaculture presents a philosophical and practical approach that seeks to repair and restore ecological balance. It can be defined as a design science that integrates traditional agricultural practices, scientific knowledge, technology, and practical skills to develop holistic solutions for human settlements in harmony with nature.

The term "permaculture" entered the literature during a time of growing awareness about the environmental and social impacts of human activity. Drawing upon earlier approaches such as permanent agriculture, soil fertility management, natural farming philosophy, and experimental agroforestry systems, the methods of permaculture evolved as a comprehensive response to these challenges.

Although permaculture originated in rural settings, it has evolved into a global grassroots movement focused on the sustainable design of human settlements in both rural and urban contexts. The core idea of permaculture is that humanity can reduce or replace energy- and pollution-intensive industrial technologies—especially in agriculture—through intentional, holistic design modeled after natural ecosystems (eco-mimicry). Its creators define permaculture as “an integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man,” presenting it as a positive response to the environmental crisis (Mollison, 1979).

By 2002, Holmgren had emphasized that permaculture is not merely about opposing problems or expecting others to enact change; rather, it is a set of ethical, pragmatic, philosophical, and technical responses based on what we can and want to do. He redefined permaculture as “consciously designed landscapes that mimic the patterns and relationships found in nature, providing abundant food, fiber, and energy to meet local needs” (Holmgren, 2002). While retaining its agricultural focus, the concept expanded to encompass broader aspects of human settlement.

Permaculture design is grounded in three core ethical principles, all centered around the well-being of the Earth and its inhabitants. Humans are at the heart of these ethics, as all actions are ultimately intended to improve human life—and the responsibility for doing so lies with humanity itself. These three ethical principles are: Care for the Earth

Care for People and Fair Share – i.e., use resources wisely and distribute surpluse quitably (Mollison, 1979).

These ethics are operationalized through twelve design principles developed by Holmgren (2002); Observe and interact, Catch and store energy, Obtain a yield, Apply self-regulation and accept feedback, Use and value renewable resources and services, Produce no waste, Design from patterns to details, Integrate rather than segregate, Use small and slow solutions, Use and value diversity, Use edges and value the marginal, Creatively use and respond to change.

These principles guide the creation of resilient, efficient, and ecologically balanced systems that align with local conditions and needs. By following them, permaculture offers a transformative framework for addressing environmental degradation, climate change, and socio-economic instability through practical, place-based, and community-centered strategies.

Permaculture design encompasses a more comprehensive way of thinking about our environment, emphasizing resource use and practical applications. It draws inspiration from patterns and processes observed in nature. The fundamental aim of permaculture design is to create stable, low-maintenance, self-sustaining systems by integrating plants, animals, and humans in a productive relationship.

The design methodology includes several sequential steps: resource analysis, observation, deduction from nature, exploring possibilities and making decisions, followed by sector and zone analyses based on efficient energy planning. The initial phase begins with listing the characteristics of each design element and constructing beneficial interconnections. This framework aims to ensure that each element serves multiple functions, and each critical function is supported by more than one element.

This first stage, known as needs and resource analysis, involves establishing functional relationships between the inputs and outputs of various components within the design. A detailed understanding of each element's characteristics, needs, outputs, and behaviors is essential for determining its optimum placement within the system in relation to other components.

Design decisions are based not only on the physical features of the land, but also on social and user-related observations. Lessons drawn from nature help determine relationships between built structures and other living elements within the landscape. The process also incorporates flexible possibilities and decisions that accommodate the interactions between various components as they evolve over time.

Before siting any structure, it is essential to analyze the characteristics of the land. Mapping topography and understanding wind and sun exposure patterns are crucial for identifying orientations that maximize benefits (e.g., passive solar gain) and mitigate adverse effects (e.g., wind protection). These data inform the sector and zone analyses, which are foundational to permaculture planning.

In sector analysis, landscape "sectors" are defined by natural and environmental forces such as sunlight, prevailing winds, rainfall, wildfire risk, and potential flooding. Through this planning tool, areas prone to wildfire, harsh winds, salt-laden or dusty winds, unwanted views, seasonal sun angles, reflected light from water bodies, or flood hazards are identified. Design strategies are then developed to position appropriate plant species and structures within each sector, enabling the effective use and direction of natural energies.

Zone analysis, on the other hand, refers to the spatial organization of elements based on how frequently they are used or require attention. Areas that need daily interaction—such as greenhouses, chicken coops, or kitchen gardens—are placed close to the home. Less frequently accessed areas, like orchards, grazing pastures, or woodlands, are located farther away. It is crucial to design from the center of human activity (usually the home) and outward, ensuring efficient energy and time use in daily routines.

The permaculture design approach is grounded in a human- and nature-centered life model, aiming for the efficient use of internal resources and local opportunities. Within this design philosophy, elements such as local climate conditions, vegetation, land use, topographic features, traditional architecture, construction techniques and details, water resources, and plant and animal systems are addressed through a holistic perspective. Embodying the philosophy of creating and sustaining a permanent culture, permaculture can serve as an effective tool in the interpretation of intangible cultural heritage, as well as in the adaptation of local knowledge and practices into contemporary systems.

The permaculture-based design approach begins with in-situ and systematic observational methods and transitions into the design phase through processes of data collection and analysis grounded in local conditions. In this process, tangible and intangible elements are evaluated simultaneously, and the mutual interaction and multi-functional utility of design components are adopted as key principles.

Permaculture design components are classified under four main categories: Land Components, Energy Components, Social Components Abstract Components.

These can be broadly grouped into tangible and intangible categories. Land and energy components represent the tangible aspects, while social and abstract components constitute the intangible dimensions of the system.

The first of the tangible components, land elements, encompass physical environmental data such as water, soil, climate, landforms, plants, and animals. Energy components include the organization of structures, infrastructure networks, the use of natural resources and energy, and technological applications.

Under the category of intangible components, social elements consist of cultural structures, human relationships, commerce, finance, and systems of mutual support. The abstract components, on the other hand, involve timing, accumulated knowledge, and ethical values.

5. The Correlation Between Historic Rural Landscape Components and Permaculture Design Elements

In this section, permaculture ethics and design components are theoretically contextualized in relation to the concept and elements of historic rural landscapes (Table 1). The permaculture ethic of *Earth Care* is directly associated with the preservation of the ecological components of historic landscapes, such as soil, water resources, and local flora and fauna. In historic areas, this principle can be applied through the restoration of authentic heritage structures, traditional water management systems, and the promotion of local ecosystem diversity. The *People Care* principle aligns with the continuation of local knowledge and cultural practices accumulated by historic rural communities. This may translate into actions such as maintaining traditional agricultural methods, preserving vernacular building techniques, and ensuring the active participation of local populations in conservation processes. The *Fair Share* ethic emphasizes the management of resources in a way that serves not only present needs but also the requirements of future generations. In the context of historic landscapes, this principle can be implemented by preventing the overexploitation of natural resources, encouraging sustainable production methods, and ensuring the use of the landscape within a socially and ecologically balanced framework.

The continuity of life and the human–land relationship—shaped through the interaction between nature and humans and reflected in rural life over centuries—represents one of the core values of rural landscapes. Natural areas, as part of the topography defined by geographic conditions, have historically guided the strategic placement of buildings and the organization of agricultural and pastoral areas. Built environments that emerged in accordance with these natural conditions constitute the cultural fabric of historic rural landscapes. Since traditional architectural structures were constructed in response to local geography and climate, they inherently possess ecological architectural qualities within their historical context. Similarly, permaculture design emphasizes the use of indigenous and local resources. In line with this, buildings in permaculture-based settlements are designed using sustainable and recyclable materials in harmony with natural systems. Efficient use of topography, as well as strategies for benefiting from or protecting against sun and wind, are achieved through a theoretical approach rooted in the same ecological perspective. The ecological structures classified under permaculture's *energy components* are characterized by their construction with natural materials suited to local climatic conditions.

Agricultural and livestock activities are central to both frameworks and constitute the agricultural environment component. One of the main criteria in determining agricultural land is its proximity to water resources to ensure fertile soil use. Forested areas forming the natural environment play a vital role in sustaining biodiversity and protecting local fauna and flora, reflecting another shared objective.

Within both design models, the built environment, agricultural environment, and natural environment are not separated by strict physical boundaries but are instead defined by their constant interaction and interdependence.

Table 1. Components of Historic Rural Landscapes and Permaculture Design Elements.

Historical Rural Landscape Components	Permaculture Design Components
Cultural Environment Land and Topography Traditional Settlement Area Transportation and Roads	Energy Components Ecological Buildings Renewable Energy Technologies
Agricultural Environment Agriculture and Farming Activities Animal Husbandry Natural Environment Forest Areas Flora and Fauna Species Water Resources	Site Components Land and Topography Climate Soil and Farming Activities Animal Husbandry Flora and Fauna Species Water Resources
Intangible Cultural Heritage	Community and Social Permaculture

Similarly, while the relationship between culture and people is associated with intangible cultural heritage in historic rural landscapes, in permaculture design it is linked to the concept of community, which centers on human and cultural activities. In line with the definition of sustainable human settlement design, permaculture aims to create nature-compatible spaces for individuals and communities, placing emphasis on community culture and lifestyle. Human relationships based on social principles are modeled on the interconnectedness observed in natural systems. From this perspective, social permaculture can be regarded as a valuable tool for engaging with the potential of intangible cultural heritage and adapting local community knowledge and practices to contemporary systems.

Conservation strategies for historic rural landscapes are expected to go beyond physical restoration and also encompass intangible cultural components such as ways of life, production systems, knowledge transmission, and social relations. At this point, there is a growing need for new theoretical approaches that transcend traditional conservation paradigms. In this context, the permaculture approach stands out as an innovative and holistic method for the sustainable conservation of rural landscapes. Permaculture design principles are of critical importance in reviving sustainable living practices in rural areas and strengthening local knowledge systems. The design process aims for maximum productivity with minimal intervention, taking into account environmental interactions and integrating topography, climate, soil structure, biodiversity, and cultural fabric (Ferguson & Lovell, 2014). In doing so, it ensures the resilience not only of natural ecosystems but also of cultural landscapes. For example, traditional water harvesting methods, polycultural agricultural systems, and the use of local building materials are practices that align closely with permaculture design principles (Altieri, 1995).

This multidimensional approach offered by permaculture in the context of sustainable conservation presents strong potential for the adaptive reuse of cultural landscapes, the strengthening of social belonging, and the revitalization of local production cycles. Moreover, by encouraging the participation of local communities in decision-making processes, this approach serves not only conservation objectives but also contributes to broader goals of rural development (Plieninger & Bieling, 2012).

6. Evaluation

The permaculture approach closely aligns with UNESCO's classification of "organically evolved landscapes" within the broader category of cultural landscapes. These types of landscapes represent systems in which long-term processes such as agricultural production, water management, and settlement patterns are integrated with natural cycles, reflecting a harmonious interaction between people and nature. Permaculture's core principles—such as working with nature, respecting soil and water cycles, and promoting production systems grounded in local knowledge and social memory—are directly related to UNESCO's emphasis on the functional and historical continuity of cultural landscapes.

UNESCO also highlights key principles for the conservation of cultural landscapes, including the participation of local communities, the continuation of traditional lifestyles, and the preservation of the area's unique character. In this regard, permaculture goes beyond a purely conservation-oriented model by offering a productive and participatory framework that fosters community engagement and social sustainability.

Similarly, the 2011 "Declaration on the Principles for Sustainability in Heritage Sites" published by ICOMOS (International Council on Monuments and Sites) introduced important principles aimed at integrating cultural heritage with sustainable development goals. These principles emphasize that heritage conservation is not merely a retrospective activity but a multidimensional process linked to social equity, environmental balance, and economic sustainability. According to ICOMOS, a sustainable conservation approach must be participatory and locally focused, respond to the socio-cultural needs of communities, adopt environmentally friendly methods of resource use, and support traditional knowledge systems and practices.

Permaculture aligns closely with these ICOMOS principles through its core values: encouraging the active participation of local people in decision-making processes; revitalizing traditional knowledge by connecting it with contemporary environmental challenges; using natural resources within closed-loop systems; and embracing an integrated design approach that encompasses natural, cultural, and productive elements.

Both UNESCO’s definition of cultural landscapes and ICOMOS’s sustainability principles emphasize multi-actor, multidimensional approaches rooted in the nature–culture relationship. Permaculture not only supports these principles but also translates them into actionable and site-specific design models. In this respect, the permaculture approach offers a flexible and transformative potential—one that is both aligned with international frameworks and adaptable to local practices.

7. Conclusion and Suggestions

Historic rural landscapes are not merely physical entities; they are holistic living environments that encompass local knowledge systems, cultural production practices, ecological cycles, and socio-economic relationships. These landscapes are the result of millennia of human–nature interaction and often reflect, either directly or indirectly, ways of life shaped by principles of sustainability. However, today’s rural areas face multifaceted threats, including rapid socio-economic transformations, urbanization pressure, climate change, tourism impacts, and legislative inadequacies. These challenges disrupt both spatial and functional continuity, increasingly rendering the cultural and natural values of rural landscapes fragile.

At this juncture, the need arises not only for restorative or static conservation approaches but also for system-based strategies that are aligned with nature. Ecological design and permaculture are critically important in this context. Both approaches emulate the functioning of natural systems, are grounded in local knowledge, and promote multicomponent, cyclical systems. Therefore, the aim in conserving historic rural landscapes should go beyond merely preserving traces of the past—it should also focus on transmitting these areas to future generations as resilient, productive, and habitable environments. In line with this vision, the following solution strategies emerge as key priorities.

Recommendations for the Built Environment:

The main issues observed in the built environment of historic rural settlements include abandonment of buildings, loss of original materials and techniques, poor-quality interventions, and the destruction of traditional fabric by modern constructions. In this context:

- Restoration efforts should be encouraged in accordance with ecological architecture principles, using local materials, climate-adapted designs, and energy-efficient solutions.
- The permaculture principles of "reuse," "reduce," and "respecting natural energy cycles" should serve as the fundamental approach in the adaptive reuse of buildings.
- New developments must prioritize context-sensitive design, respect traditional silhouettes, and maintain architectural continuity. Participatory planning processes involving local communities in conservation decisions will enhance social ownership.
- Furthermore, it is necessary to officially register areas that meet the cultural landscape criteria and expand their protection status legally.

Recommendations for the Agricultural Environment:

Functional losses in agricultural areas, industrialization of production methods, and the fading of traditional knowledge systems are causing transformations in the character of rural landscapes. In this regard:

- The permaculture zoning system enables planning production areas according to topography, water regime, and soil structure, thus optimizing the use of the land's natural potential.
- Practices such as polyculture, compost production, rainwater harvesting systems, and food forests contribute both to biodiversity conservation and soil vitality.
- Structures like educational farms, local seed networks, and women's cooperatives should be strengthened to document, revive, and transmit traditional production systems across generations.
- Regaining the productivity of agricultural lands will help reverse rural outmigration and contribute to economic sustainability.

Recommendations for the Natural Environment:

Problems such as climate change impacts, habitat loss, and environmental pollution are weakening the natural support systems of rural areas. Accordingly:

- One of permaculture's core principles—working in harmony with nature—requires design approaches in rural landscapes that respect soil, water, and plant relationships.
- Water management systems (rainwater harvesting, grey water recycling, natural treatment systems) should be established and integrated with agricultural and built environments.

- Windbreak tree plantings, habitat restoration using native species, and wildlife corridors contribute to biodiversity conservation.
- Natural areas should be addressed through comprehensive landscape planning rather than fragmentation, with ecological networks established to strengthen connectivity.

Conservation is not merely about preserving the past but also about shaping the future. In this spirit, the proposed permaculture and ecology-based approach to protecting historic rural landscapes links restoration with productivity, conservation with life cycles, and planning with participation. Thus, historic rural areas can transform from mere heritage sites into vibrant, functional, and resilient living environments.

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The Relationship Between Energy and Spatial Planning in Türkiye's Development Policies

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1. Introduction

Energy isn’t just about technical infrastructure; it's also a key factor in social welfare, economic growth, and environmental sustainability (Özdağ, 2023; Srinivasu & Rao, 2013). Rising energy demand, urban growth, and the global climate crisis have made the relationship between energy planning and spatial planning even more important (Baş & Partigöç, 2022; De Pascali & Bagaini, 2018). Especially in countries where urbanization is speeding up and consumption-focused development policies are in place, the importance of managing energy demand alongside planning decisions is growing (Singh, Roy, Spiess, & Venkatesh, 2015; Un-Habitat, 2022).

Türkiye is experiencing a substantial increase in energy consumption, attributable to its expanding industry and demographic growth (Kahraman, 2019). However, its reliance on external energy supplies raises economic vulnerabilities and makes energy security a strategic concern (Konca, 2018). As of 2022, about 70% of Türkiye's total primary energy supply will come from imports, requiring a shift to domestic and renewable resources in the energy sector (EPDK (Enerji Piyasası Düzenleme Kurumu), 2023; ETKB, 2023; TSKB, 2023). This transformation process directly impacts not only energy production technologies but also spatial decision-making processes such as urban planning, land use, transportation, and building design. In this context, it is expected that the role of energy will become more apparent within the spatial planning system and that there will be a planning approach that integrates it with sustainable development goals (Stoeglehner, Niemetz, & Kettl, 2011). Specifically, the 11^{th} (2019–2023) and 12^{th} Development Plans (2024–

2028) in Türkiye have incorporated the energy-space relationship into policy documents with themes such as “green transformation,” “clean energy technologies,” “energy efficiency,” and “carbon-free development” (Sagbaş & Başbuğ, 2018). However, how this representation is reflected in planning practice and the extent to which it can be integrated into the current planning system remains controversial.

This book chapter examines Türkiye's energy landscape and explores the theoretical dimensions of the relationships between energy planning and spatial planning. It explores how energy fits into development plans, how energy-related decisions are made in the national planning system, and how these decisions show up in the spatial layout of cities. The study also aims to contribute to a planning approach that balances energy security, efficiency, and environmental sustainability by developing a comprehensive, systematic proposal for energy-focused spatial planning.

1.1. The Relationship Between Energy and Spatial Planning

Energy and space are central to urban planning and sustainable development policies as two components that influence each other (Everding, Genske, & Ruff, 2025). Spaces directly influence energy structures, location choices for energy production, transmission line routes, density of consumption centers, and the effectiveness of energy efficiency measures (Steemers, 2003). Similarly, technological and economic progress in energy infrastructure also influence how space is built and changed (Lang, 2018).

Energy infrastructures are primarily designed around spatial requirements. Power plants, wind and solar farms, energy transmission lines, pipelines, and distribution centers must be situated within a designated geographic area (Lu et al., 2025). This location choice depends on spatial factors such as topography, proximity to natural resources, existing infrastructure connections, and environmental protection areas. For example, installing large-scale solar power plants (SPPs) needs large, flat areas that are always sunny and free of ecological risks (Al Garni & Awasthi, 2018; Kereush & Perovych, 2017; Steemers, 2003). This creates new conflicts in rural planning. At the urban level, the spatial distribution of energy demand is connected to factors such as construction patterns, transportation systems, and population density (Şekeroğlu, Özkaynak, Yeşilyurt Alkan & Başkan, 2021). Energy consumption is usually higher in densely developed areas; however, these locations also provide benefits for installing centralized systems and applying energy efficiency solutions (Chang, 2015). The impact of transportation systems on energy use cannot be ignored; increased individual vehicle use due to unplanned urbanization raises fossil fuel-based energy consumption and carbon emissions (IEA, 2021).

However, the effect of urban planning decisions on energy depends not only on consumption but also on assessing energy efficiency and renewable energy potential (Mirakyan & De Guio, 2013). Building orientation, façade design, green infrastructure strategies, and land use decisions can directly influence energy consumption levels (Krüger & Kolbe, 2012). Therefore, the relationship between energy and space is a planning issue that must be assessed from multiple dimensions, across disciplines, and with a strategic approach.

The “energy-informed planning" approach, which is becoming increasingly popular today, assesses this relationship from a more comprehensive perspective by suggesting the integration of energy supply and demand with spatial strategies (Dong, Zhang, Calinon & Pokorny, 2025; Yu et al., 2021). This approach aims to integrate energy infrastructure with ecosystems, urban form, and social structures, making the planning discipline an active participant in the energy transition.

1.2. Türkiye's Energy Outlook

Türkiye’s energy landscape is constantly changing due to economic growth, urbanization, industrialization, and population increase. Growing energy demands and external reliance are pushing Türkiye to adjust its energy policy to focus on both supply security and sustainability (Kantörün, 2010) . In this context, the energy sector has become a strategic area not only economically but also environmentally, socially, and in spatial planning.

As of 2023, Türkiye's total primary energy supply is around 158.4 million TEP (Tonnes of Oil Equivalent) (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2024b). The main sources of energy supply are oil with 40 million toe, natural gas with 41.5 million toe, renewable energy with 28.7 million toe, and others (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2024b). This distribution indicates that Türkiye's energy system remains primarily reliant on fossil fuels.

In terms of energy use, total final energy consumption in 2023 was about 121.5 million TEP. In the sectoral distribution of consumption, industry ranks first with 30.3%, followed by transportation at 27.4%, housing at 21.8%, the service sector with 10.5%, and agriculture at 4.5% (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2024b). This table shows that energy-intensive sectors like industry, transportation, and residences are key components that need to be considered in spatial planning.

Türkiye's energy production reached 51.2 million TOE in 2023, with about 65% of its energy supplied through imports (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2023). High levels of external dependence, especially on natural gas and oil, reveal a structural weakness in energy security (IEA, 2025). To reduce this dependency, policies are being put into place to boost the use of domestic and renewable energy sources (Günay & Yildirim, 2024; Yalçın & Dogan, 2023). Investments in renewable energy in Türkiye have grown considerably in recent years. As of February 2024, data shows that renewable energy makes up 56.21% of Türkiye's total installed capacity. The source distribution is as follows: hydroelectric 29.73%, wind 11.12%, solar 11.5%, biomass 2.24%, and geothermal 1.57% (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2024a). New investments, especially in solar and wind energy, institutionalized through the YEKA (Renewable Energy Resource Area) model, directly influence land use decisions at the planning scale (TSKB, 2023). With this, Türkiye has also entered a new era in nuclear energy. The Akkuyu Nuclear Power Plant (NPP), Türkiye's first nuclear facility, has four units, each with a capacity of 1,200 MW. Once fully operational, the plant is expected to supply 10% of Türkiye's electricity needs, with a total capacity of around 4,800 MW (Akkuyu Nükleer, 2025). The introduction of nuclear energy serves a strategic role in ensuring supply security and reducing carbon emissions.

Investments and strategies in the energy sector also influence spatial planning systems. The placement of energy infrastructure, development of renewable energy zones, and environmental and urban effects of strategic investments like nuclear energy require an integrated approach to energy planning. Therefore, Türkiye's energy policies need to be evaluated not only for their technical aspects but also for their spatial considerations effects.

2. Material and Method

This study aims to analyze the historical evolution of Türkiye's energy policies through development plans, evaluate the connection between these policies and spatial planning systems, and develop strategic scenarios for the future. Within this framework, the research uses a combination of qualitative methods, including document analysis and content analysis.

To assess the Energy and Spatial Planning system, key terms and their explanations are identified within the scope of the evaluation (Table 1). Each Development Plan document (from the 1st to the 12th Plan) was reviewed in the thematic area based on the key concepts of "spatial planning," "environmental planning," "land use," "regional development," "location selection," "infrastructure investment," "regional energy planning," "urban energy planning," and "energy and climate-compatible planning" to examine the connection between Energy and Spatial Planning. The context and situations where these concepts are included in the plans are explained.

Table 1. Key Phrase Identified for Investigating Spatial Planning Systematics and Energy.

Key Phrase	Brief Description (Policy/Thematic Area)
Spatial Planning	Integration of energy investments into national and regional plans, multi-scale synchronization
Environmental Planning	Relationship of energy projects with physical plans compatible with environmental impacts

Land Use	Relationship of energy projects with land classes (agriculture, forestry, etc.)
Regional Development	Directing energy investments to underdeveloped regions and infrastructure balance
Location Selection	Environmental, social, and technical location criteria in energy projects
Infrastructure Investment	Integrated planning of energy infrastructure with transportation, water, etc. systems
Regional Energy Planning	Renewable energy zones and regional energy supply-demand balance
Urban Energy Planning	Energy efficiency in cities, energy management with building and transportation systems
Energy and Climate Compatible Planning	Integration of energy infrastructure and green transformation compatible with climate targets

The frequency of the concepts, their contextual use, and their impact on policy recommendations are then periodically analyzed using a sequential analysis method. The presence of expressions evoking the relationship between "spatial planning and energy" in each plan is presented from a general perspective. The explanations for the expressions used in the table to be created are as follows:

"+" expression: The concept is present.

"++" expression: The concept is present directly and strongly.

"x" expression: The concept is absent / very indirect.

This research examines National Development Plans across three periods for more detail:

- 1^{st}–5^{th} Plans (1963–1984): The start of planned development, centralized energy investments, and the initial environmental regulation efforts;
- 6^{th}–10^{th} Plans (1990–2004): Liberal transformation, privatization policies, and increased environmental efforts awareness;

- 11th –12th Plans (2019–2028): Focus on sustainability, green transformation, regional energy integration, and climate initiatives planning.

The relationship between energy and spatial planning components and policy integration is explained for each period.

The final section of the study performs a future-focused scenario analysis based on historical data, providing insights into how Türkiye's energy-spatial policies should be developed in terms of sustainability, regional balance, and infrastructure strategies. This approach aims to offer a strategic plan for decision-makers working at the crossroads of spatial planning and energy policies.

3. Findings and Discussion

3.1. Development of the Relationship between Energy and Spatial Planning from a Periodic Perspective

Based on analyses from the 1st to the 12th Development Plan, the historical development of the relationship between energy and spatial planning is examined in periodic groups. Findings are discussed according to key concepts and themes identified in each period.

Energy was viewed as a key resource for economic growth in Türkiye's development planning between 1963 and 1989. This was a period during which energy infrastructure was developed based on production and supply, with sectoral objectives prioritized over spatial integrity and environmental considerations strategies. A direct and institutional connection between spatial planning and energy planning was not established, and indirect relationships stayed limited (Table 2).

Table 2. Relationship between the 1st and 5th Development Plans and Key Term.

Key term	1st Plan (1963–1967)	2nd Plan (1968–1972)	3rd Plan (1973–1977)	4th Plan (1979–1983)	5th Plan (1985–1989)
Spatial Planning	Indirect: With TEK, electricity infrastructure is expanding to rural areas.	Indirect: As industrial infrastructure grows, a connection with settlements is being established.	Indirect: Emphasis on spatial distribution of energy resources	Weak: Limited explicit spatial emphasis on infrastructure distribution	Indirect: The role of the private sector in energy investments creates a need for planning.
Environmental Planning	None	None	None	None	None
Land Use	Natural resources are taken into consideration when selecting the location of energy production centers.	Land use discrimination is being discussed in the transition to commercial energy.	Land use recommended for energy resources (hydro, geothermal, nuclear)	Power plant location recommendations based on land resources	Low emphasis on land use.
Regional Development	Low: Limited industrial infrastructure, regional focus.	Medium: Efforts are being made to direct industrial investments to regions along with energy.	Medium-high: Energy infrastructure planning for mining and industry	Medium: Discussions on local infrastructure and energy linkages	Medium-high: Regional role of energy in industrialization infrastructure.
Location Selection	Indirect location selection based on renewable resources (dams, thermal power).	None	Yes: Recommended location choices for geothermal and nuclear energy	None	None
Infrastructure Investment	High: Dam and thermal power infrastructure investments.	Medium: Natural gas and oil infrastructure is being planned.	High: Focus on investment in electrical infrastructure	Medium: Focused emphasis on local infrastructure	Medium: Thermal and hydropower investments are prominent.
Regional Energy Planning	None	None	None	None	None
Urban Energy Planning	None	None	None	None	None
Energy and Climate Compatible Planning	None	None	None	None	None

The relationship between energy and spatial planning has changed noticeably in development plans since 1990. As the environmental aspect of spatial planning has gained importance, energy infrastructure has been regarded as critical infrastructure. Environmental plans have been incorporated into planning processes since the 2000s and have become more significant with green growth strategies. While renewable energy zones have become prominent in land use and location selection, infrastructure investments have increased, especially after privatization. The idea of regional energy planning emerged during this period but remains at the proposal stage. Urban energy planning has recently become a focal point in the context of smart cities and sustainable urban development. Energy and climate-friendly planning has evolved alongside sustainability and green transformation since the 1990s. Overall, this period marks a transition phase in which the foundations for integrating energy and spatial planning are established, and environmental and sustainability concerns are incorporated into planning language (Table 3).

Table 3. Relationship between the 6th and 10th Development Plans and Key Term.

Key term	**6th Plan (1990–1994)**	**7th Plan (1996–2000)**	**8th Plan (2001–2005)**	**9th Plan (2007–2013)**	**10th Plan (2014–2018)**
Spatial Planning	Initial environmental planning concepts; energy infrastructure is considered critical infrastructure.	The concept of sustainable development is entering Türkiye.	The energy sector is liberalizing, planning is becoming more flexible.	Renewables and energy efficiency are at the forefront.	Smart city and sustainable urbanization are increasing.
Environmental Planning	None yet.	None	Weak; environmental sub-planning is in transition.	Weak–Moderate; few regional plan references.	Yes; aligns with green growth and climate plans.
Land Use	First land use observed in hydropower regions.	Renewable resources (geothermal, wind power plants) are attracting attention.	Pre-YEKA spatial planning initiatives, hydro/PV.	Land discussions for solar power plants and wind power plants.	Land integration in energy and water infrastructure plans.

Regional Development	Medium; the impact of infrastructure investments on regional development is emphasized.	Medium-high; relationship between renewable resources and sub-regional development.	High; renewable investments are being directed towards regional development.	High; regional development with renewable energy contributions.	High; renewable infrastructure's contribution to regional development is growing.
Location Selection	No direct emphasis.	None	Initial criteria discussions in the initial phase.	Yes; site selection criteria are beginning to emerge.	Clear; site selection criteria for nuclear and solar power plants are clear.
Infrastructure Investment	High; TEK infrastructure is being expanded.	Medium; infrastructure growth continues.	High; post-privatization infrastructure investments are intense.	High; infrastructure expansion (communications, grid).	Very high; comprehensive infrastructure planning recommendations.
Regional Energy Planning	None	None	Initial phase; regional planning definition is mentioned for the first time.	Medium; energy planning is being defined for the first time.	Medium; regional energy planning model recommendations.
Urban Energy Planning	None	None	None.	None.	Increasing; urban energy planning definitions.
Energy and Climate Compatible Planning	First environmental sensitivity statements.	Emphasis on sustainability.	Low; emphasis on environmental sustainability.	Medium: energy efficiency and environmental themes.	Medium; green transformation concept included.

The 11th and 12th Development Plans demonstrate significant progress in the connection between energy and spatial planning. Spatial planning clearly stresses the importance of aligning energy investments with environmental plans, and land use and site selection criteria are detailed, especially in renewable energy and nuclear energy sectors. Although regional development and infrastructure investments are closely linked to energy-focused strategies, regional energy planning has become essential. Urban energy planning is being integrated with the smart city concept in the 11th Plan. Energy and climate-compatible planning themes, including a focus on net zero and efficiency, remain prominent. The 11th and 12th

Development Plans seem to thoroughly cover Türkiye's energy policies from a spatial and sustainability perspective (Table 4).

Table 4. Relationship between the 11th and 12th Development Plans and Key Term.

Key term	11th Plan (2019–2023)	12th Plan (2024–2028)
Spatial Planning	A clear spatial perspective on energy; reference to the national CDP strategy	Integrating energy into spatial planning is a strategic goal.
Environmental Planning	Energy investments must be compatible with the CDP	CDP clearly articulates energy infrastructure integration.
Land Use	Land planning for YEKA areas and nuclear power plant surroundings is clear	New land plans for hydrogen and storage systems.
Regional Development	High relevance to energy resources in local development policies	Energy policies are highly integrated with regional strategic plans.
Location Selection	Akkuyu and solar power plant location selection criteria are clear	Nuclear, storage, and wind power plant location selection criteria are critically included in official documents.
Infrastructure Investment	Smart grid and energy infrastructure investments are a high priority	Infrastructure strategies are highly detailed in plan documents.
Regional Energy Planning	Renewable energy zones are being structured	The obligation for regional energy planning has been officially stated.
Urban Energy Planning	Moderately integrated into urbanization with the smart city concept	(No direct statement yet; a focus on this issue can be expected in the 12th Plan details.)
Energy and Climate Compatible Planning	Energy efficiency and net-zero are at the forefront	The scope of energy and climate-compatible planning continues to grow.

If we assess the relationship between spatial planning and energy in the National Development Plans using a sequential analysis from a general perspective, the importance of the connection between energy and spatial planning has become increasingly significant throughout history (Table 5). In the initial planning phases, energy infrastructure was indirectly incorporated into the spatial plan, mainly through rural industrial investments, while environmental plans and land use concerns were rarely emphasized. Since the 1990s, due to the rise in sustainable development and environmental concerns, significant progress has been made in environmental planning and land use; the integration of renewable energy sites into spatial planning has become more prominent.

With liberalization and technological advances in the 2000s, the role of energy investments in regional planning has grown, and the ideas of comprehensive planning and energy efficiency are discussed more often in infrastructure investments. Recent plans systematically and comprehensively address the integration of energy and spatial planning in accordance with national strategies (Environmental Planning, Net Zero Emissions targets). It plays a vital role, especially in regional energy planning, urban energy policies, and climate-compatible energy transition processes. This transformation indicates that the spatial aspect of Türkiye's energy policies is increasingly influenced by a more strategic and integrated approach.

Table 5. Sequential Analysis of the Relationship between National Development Plans and Key Terms.

KT	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**
SP	x	+	+	++	++	+	+	++	++	++	++	++
EP	x	x	x	x	+	+	+	++	++	++	++	++
LU	x	+	+	+	++	+	+	++	++	++	++	++
RD	+	+	++	++	++	++	++	++	++	++	++	++
LS	x	+	+	++	++	+	+	++	++	++	++	++
II	++	++	++	++	++	++	++	++	++	++	++	++
REP	x	x	x	x	+	x	+	+	++	++	++	++
UEP	x	x	x	x	x	x	x	x	x	+	++	++
ECCP	x	x	x	x	x	+	+	+	+	++	++	++

Note: To summarize the key terms used in this study, their initials are abbreviated in the table. The numbers 1 through 12 correspond sequentially to the respective Development.

3.2. Türkiye’s Future Energy and Spatial Planning Scenario and Its Compliance with International Policies

3.2.1. Türkiye’s future scenario for energy and spatial planning

When evaluating Türkiye's energy and spatial planning development from 1963 through the 12th Development Plan, the relationship between energy production and economic growth was addressed through production and distribution infrastructure in the 1st and 5th Development Plans of 1963-1995, with environmental compliance and social impact being limited. The 6th and 10th Development Plans from 1995 to 2015 were linked to sustainability goals. The 11th and 12th Development Plans from 2015 to 2028 more comprehensively addressed the integration of energy and spatial planning, including concepts like green transformation, climate-compatible urbanization, net-zero targets, smart energy infrastructure, and regional planning. In Türkiye's national development process, energy investments aimed at development should be integrated not only with sectoral plans focused on the economy but also with a multi-dimensional spatial planning approach that considers physical, environmental, and social impacts.

The global significance of energy policies for Türkiye's national development, and their integration with spatial planning systems to realize these policies, are issues that need further development in the future. In this context, a National Spatial Energy Planning Framework should be established in Türkiye, similar to international examples (Bundesnetzagentur, 2025; Gouvernement, 2025).

Based on the key concepts identified in the research, two main themes emerge for integrating energy and spatial planning. These are regional and urban multi-scale energy planning, energy and climate-resilient planning, and location selection. These concepts should also serve as the foundation for National Spatial Energy Planning.

- **Regional and urban multi-scale energy planning**

The energy supply and demand balance should be integrated with regional and urban development objectives. An energy forecast that accounts for the spatial potential and thresholds of renewable, nuclear, and other energy resource investments is expected. Advanced technologies like regional and urban-scale databases and decision support systems should be incorporated into planning processes. The spatial implications of energy targets should be clarified during planning stages. Data sharing between institutions, scenario sharing, and standardized spatial analysis practices should be established.

- **Energy and climate-resilient planning, and location selection**

The selection of locations for energy production facilities (hydroelectric, nuclear, solar, wind, and storage systems) should consider environmental capacity, disaster risks, ecosystem services, and social impacts. Environmentally responsible analysis processes, especially for large-scale energy projects like nuclear power plants, should be created and directly incorporated into the planning system. Furthermore, energy-efficient building designs, innovative carbon-reducing solutions in transportation systems, and green infrastructure should be prioritized across all urban and regional levels. National energy planning should connect to climate change adaptation, environmental impact assessments, and urban resilience strategies. Energy Impact Assessment practices should be created and incorporated into planning processes.

3.2.2. Compliance with international policies

Global policies related to energy and spatial planning include, in particular, the European Union's Green Deal, the United Nations' Sustainable Development Goals (SDG 7, SDG 11), and the International Energy Agency's net-zero emissions scenarios. Concepts such as energy system sustainability, energy efficiency, transitioning to renewable energy sources, and regional energy justice are among the current topics in these global policies (European Commission, 2025c).

The European Union's "REPowerEU" strategy promotes identifying renewable energy zones in spatial planning, integrating digital twin systems into urban development, and creating energy-climate compatible settlement policies (European Commission, 2025b). Aligned with the EU's 2050 carbon neutrality goal, the environmentally sustainable transformation of energy infrastructures has been prioritized in spatial planning processes (European Commission, 2025a). Türkiye's 2021 Green Deal Action Plan demonstrates compliance with this process, but this transformation has yet to evolve into a comprehensive spatial strategy in current development plans (T.C. Ticaret Bakanlığı, 2021). Specifically, land use, urban energy planning, and the placement of renewable infrastructure must follow practices fully aligned with EU directives. SDG 7 (Clean Energy) and SDG 11 (Sustainable Cities) require the integration of energy planning with settlement strategies (UNDP, 2025) . While progress has been made in the 11th and 12th Development Plans towards this integration, challenges such as climate-adaptive spatial scenario creation, risk-based settlement planning, and spatial analysis of energy access disparities still need to be addressed. The IEA recommends shifting to spatial data-driven energy planning in areas like city-scale energy scenarios, electric vehicle infrastructure, spatial management of distributed generation systems, and smart grid planning (IEA, 2021). The process that began with COP21 (Paris Agreement) emphasizes that spatial planning should be compatible with climate goals (T.C. Dışişleri Bakanlığı, 2025). Türkiye's 2053 Net Zero commitment and 2021 ratification of the Paris Agreement are reflected in its development plans. However, tools like carbon budgeting, climate risk mapping, and location selection using greenhouse gas intensity analyses, which are required by the COP process within the spatial planning system, are not yet widespread in Türkiye.

Evaluations of Türkiye's national development plans show that it has started supporting these policies in recent years. Creating a National Spatial Energy Planning Framework would greatly help develop policy tools aligned with these initiatives strategies.

Therefore, the future development of Türkiye's spatial planning system will depend not only on internal factors but also on its ability to align with international energy transition policies and climate goals. In this context, it is necessary to develop integrated data infrastructures at the national level, digitize planning and management processes, and align them with international technical standards and practices.

4. Conclusion and Suggestions

This study explores the connection between energy and spatial planning within the framework of Türkiye's development policies from a historical perspective and analyzes how these two areas have become integrated over time. Over the course from the planning practice that began in 1963 to the present, it is evident that the effort to achieve closer integration with the spatial planning system has evolved alongside the growing strategic significance of energy investments in development policies.

The findings reveal that the relationship between energy planning and spatial planning systems in Türkiye can be categorized into three evolutionary periods. These are the initial periods focused on infrastructure, the transition period based on sustainability, and the current era dominated by the vision of an integrated carbon-neutral future. Trends projected for the 12th Development Plan and beyond show that energy policies are no longer solely focused on supply security or production efficiency; they also aim to achieve multiple objectives such as environmental sustainability, fighting climate change, and reducing regional development gaps.

At the international level, Türkiye's energy and planning policies are increasingly aligned with global frameworks like the European Union Green Deal, the United Nations Sustainable Development Goals, and the Paris Climate Agreement. To institutionalize this harmony, the legal and administrative framework for spatial energy planning must be clearly established, multi-scale and data-driven planning mechanisms need to be put in place, and social integration and local participation processes should be strengthened.

In this context, the primary contribution of the study is to demonstrate that energy investments should be evaluated not solely on their technical and economic dimensions, but also considering their spatial, environmental, and social impacts. Future research may scrutinize in greater detail the applicability of spatial energy planning at the local government level, including its technological infrastructure requirements and its influence on regional disparities. Furthermore, the role of large-scale investments, such as nuclear energy, within spatial strategies and their social acceptance processes remains a significant area for ongoing research in the forthcoming period.

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Innovative Approaches to Adobe: Rethinking Earthen Materials for Sustainable Urban Futures

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1. Introduction

With the advancement of technology, the production of modern building materials has increased, leading to environmental pollution due to resource consumption, waste generation, and emissions throughout their life cycle. While the numerous advantages of modern building materials are undeniable, factors such as health, environmental impacts, psychological factors, and economic costs, along with the need to conserve energy resources and the responsibility of leaving a liveable world for future generations, have encouraged many countries to turn to building materials that require less energy in their production and use (Bozyel, 2021; Leblebiciler & Akıncı, 2021).

Adobe brick, obtained from nature and used throughout history, has once again become a focus of interest due to its affordability, ease of production without the need for complex facilities, accessibility and sustainable properties (Öztürk, 2020). In addition to its high sound absorption capacity and heat storage ability, adobe also contributes to indoor comfort by balancing heat transfer. However, its low compressive strength and poor resistance to water are significant limitations that considerably restrict its use (Güneri, 2023). Factors such as the perception of insufficient material capabilities, a lack of confidence in the material, and the limited awareness of adobe in contemporary architectural design are among the elements that reduce its use in both urban and rural architecture (Gelirli, 2022).

Although the use of adobe is decreasing today, it is still preferred in many parts of the world. While existing adobe structures are considered a historical legacy, contemporary structures continue to be built using this material (Bozyel, 2021). In this context, studies on reducing the negative aspects of adobe buildings have increased in recent years, and research has been carried out to increase the potential of adobe in architecture through contemporary construction methods (Yardımlı, 2021).

This study aims to examine innovative approaches to developing adobe within the context of contemporary architecture and building technologies. The study explores modern methods aimed at improving the properties of adobe, including enhancing material strength through additives, reinforcing structural stability through support systems, and applying innovative production techniques. These approaches are illustrated by examples of their application in modern buildings. In addition, the study evaluates the potential for the renewed use and further development of adobe in both Türkiye and internationally.

2. Innovative Approaches to Adobe Material

Innovative approaches to adobe structures include improving the composition of adobe, reinforcing adobe buildings through structural support systems, and applying innovative production techniques.

2.1. Development of the Composition of Adobe

Beyond its traditional use, adobe is currently being studied in combination with various additives to support its modern application. These studies aim to enhance the durability of adobe and make it more suitable for contemporary construction needs (Olğun & Karatosun, 2023). In this direction, research is being carried out with natural additives and protective substances. Straw is a primary binder used in adobe production, helping to bind a mixture of clay and sand. Rice or wheat straw is typically used. The combination of water and organic matter, straw, with the inorganic soil results in a chemical reaction. This reaction affects adobe's durability and resistance to pressure. A lack of straw can lead to cracking in the adobe (Elborgy, 2019).

Apart from studies focusing on fibre additives, most research has concentrated on improving the physical and mechanical properties of adobe by adding binders and stabilizers. Gypsum, cement, and lime are among the primary additives used to improve and stabilize adobe mixtures. The use of these materials is not a recent practice; they have historically been employed in various construction applications, particularly in buildings, roads, and foundations. The main purpose of using such additives is to reduce the curing and drying requirements and duration of the material (Gelirli, 2022). The observed effects of binder and fibre additives on mechanical properties, water resistance, and thermal performance are shown in Table 1. Positive effects are indicated with a "+" sign, while cases showing no significant change or lacking data are marked with a "-" sign (Table 1).

Recent studies have shown that the addition of various additives into adobe can effectively improve its mechanical strength, water resistance, and thermal properties. By enhancing the material’s durability, these additives help expand the range of applications of adobe. Moreover, when such improvements are achieved using natural and locally sourced materials, they hold great significance in terms of environmental sustainability.

Table 1. Studies Conducted with Fibre and Binder Additives.

Study	Year	Fiber Reinforcement	Binding Contribution	Mechanical Properties	Water Resistance	Thermal Properties
Millogo et al.,	2014	Hibiscus Fiber		+	-	-
Serrano et al.,	2016	Corn Plant Meadow Grass		+	-	-
Millogo et al.,	2016	Cow Manure		+	+	-
Lokeshwari and Jagadish,	2016		Granite Waste Cement	+	-	-
Lanzon et al.,	2017		Zinc Stearate	+	+	-
Pekrioglu Balkis,	2017	Polymer Fiber	Waste Marble Dust Plaster Lime	+	-	-
Araya-Letelier et al.,	2018	Pig Bristle		+	-	-
Omar Sore et al.,	2018		Geopolymer	+	-	+
Kafodya et al.,	2019	Sisal Fiber Fiber		+	-	-
Gandia et al.,	2019	Glass Fiber Reinforcement		+	+	+
Berkgil and Ayaz,	2019	Polypropylene Fiber		+	-	-
Elborgy,	2019	Palm Fiber		+	+	-
Munoz et al.,	2019	Paper and Pulp Residue		+	+	+
Babe et al.,	2021	Neem Wood Fiber		+	-	+
Ige and Danso,	2021	Banana Fiber		+	-	+
Leblebicier and Akıncı,	2021	Organic Fiber	Pumice, Gypsum, Slaked Lime, Volcanic Tuff,	+	-	+
MinhTrang et al.,	2021		Sludge, Fly Ash and Fiber	+	-	-

Study	Year	Fiber Reinforcement	Binding Contribution	Mechanical Properties	Water Resistance	Thermal Properties
MinhTrang et al.,	2021		Sludge, Fly Ash and Fiber	+	-	-
Dominguez -Santos and Bravo,	2022	Polyethylene Fiber		+	-	-
Alkadri,	2022	Paper Waste		+	-	-
Lara-Ojeda et al.,	2022		Zeolite	+	+	-
Morsy et al.,	2022		Rice Straw Ash Sodium Hydroxide	+	+	+
Eslami,	2023	Palm Fiber		+	-	-
Güneri,	2023	Sunflower Stalk		+	+	
Zarasvand et al.,	2023		Wood Ash Bentonite Cement	+	-	+
Paul et al.,	2023	Rice Husks	Ash -Cement	+	-	-
Sanou,	2024	Coconut Fiber	Cement	+	-	+
Bölükbaşı,	2024		Nano Clay	+	-	-

2.2. Strengthening Adobe Buildings with Structural Support Systems

Adobe buildings are highly vulnerable to natural disasters such as earthquakes. During earthquakes, these structures are subjected to high seismic forces and, unable to withstand these forces, experience collapse. In 2001, earthquakes in El Salvador and Peru led to the collapse of numerous adobe buildings, resulting in significant loss of life. (Government of Nepal, UNDP & CoRD, 2016). Similarly, the 2010 earthquake in Elâzığ, Türkiye, caused serious damage to adobe structures, with many buildings either collapsing or being largely destroyed, resulting in the loss of 41 lives (Binici, Durgun & Yardım, 2010).

Various reinforcement techniques have been developed to improve the seismic performance of adobe structures. These methods involve the application of systems composed of flexible and low-cost materials—such as steel meshes, polymer-based meshes, polypropylene fibres, and bamboo lattices—to structural walls (Figure 1). These methods aim to enhance the energy dissipation capacity of the structure during earthquakes, preserve the integrity of load-bearing elements, and prevent overall collapse. The use of local materials, which offer advantages such as ease of application and low cost, makes these reinforcement techniques a valuable alternative, particularly in resource-constrained regions (Sathiparan, 2015).

Figure 1. Installing Vertical Mesh Strips at Corners (Quiun, 2009).

Although traditional reinforcement methods exist to enhance the strength of wall assemblies, recent research has explored alternative strengthening techniques to prevent collapse and reducing loss of life during earthquakes (Sathiparan, 2015). In response to the low strength and brittle nature of adobe structures, a 2024 study investigated the in-plane behaviour of adobe walls reinforced with bamboo mesh strips and jute threads (Figure 2). The findings showed significant improvements in compressive strength, shear strength, and energy absorption capacity (Aizaz et al., 2024).

Figure 2. Compression Tests (Aizaz et al., 2024).

In another study conducted in 2019, the seismic performance of adobe structures reinforced with steel and synthetic meshes was evaluated(Figure 3). The findings indicated that such reinforcement could enhance both horizontal (in-plane) strength and vertical (out-of-plane) load-bearing capacity. (Reyes et al., 2019).

Figure 3. Strength Tests Performed on the Sample Placed on the Steel Mesh (Reyes et al., 2019).

2.3. Innovative Adobe Production Techniques

Modern adobe production techniques include the use of various machines, 3D printing, digital compression, and bio-injection systems. Adobe blocks can also be produced using an innovative, adaptable mold-casting mechanism (Figure 4). A study using adobe mixed with cement has shown that this technique offers long-term environmental and cost advantages compared to traditional methods (Kontovourkis & Konatzii, 2021).

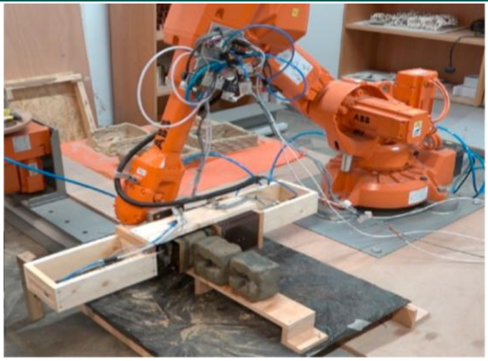

Figure 4. Mold Casting Mechanism (Kontovourkis & Konatzii, 2021).

Adobe blocks can be manufactured in factory using an extruder(Figure 5). In this technique, stabilized earth mortar is passed through a machine that shapes it as desired. The blocks are typically hollow in design. This method enables the production of homogeneous and smooth adobe blocks. (Gelirli, 2022).

Figure 5. Soil Blocks Produced with an Extruder (Gelirli, 2022).

Hydraulic press machines can be used in adobe brick production to achieve higher quality, smoother surfaces, and various designs(Figure 6). In a recent study, mud, fly ash, fibres, and aggregates were utilized, supplemented by additives and binders such as cement, liquid glass, and polypropylene fibers. These materials were added into the adobe in specific proportions, resulting in improvements in both compressive and flexural strength (Minh Trang, Dao Ho, & Babel, 2021).

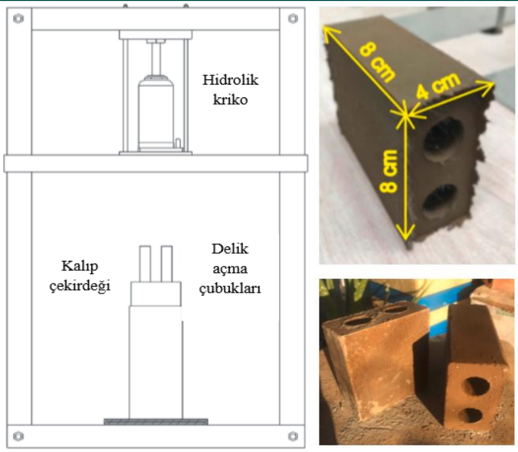

Figure 6. Hydrostatic Press System and Brick States Before/After Compression (Minh Trang et al., 2021).

Extrusion, one of the digital fabrication methods, is based on the principle of 3D printing a material. Initially developed through pottery printing using clay, this technology has since been applied to the construction of large-scale buildings using earth-based materials (Schweiker et al., 2021). Accordingly, various prototype studies have been developed to evaluate the applicability of soil-based materials with 3D printing technologies.

The project, aiming to explore the potential of 3D printing technologies for living spaces, produced a five-meter-high performative wall prototype using adobe bricks, adapted to local structural and climatic conditions Schweiker et al., 2021) (Figure 7).

Figure 7. Digital Adobe Wall Prototype (Dubor, Marengo, & Ros-Fernandez, 2019).

In 2019, an adobe wall model incorporating a wooden staircase was designed using 3D printing technology to investigate the load-bearing capacity of adobe. The material used in the project was prepared from a mixture of soil, water, rice straw, rice husks, and lime (Gomaa, Jabi, Soebarto, & Xie, 2022) (Figure 8).

Figure 8. Wall Created with 3D Printing (Gomaa et al., 2022).

Compressed earth walls can be produced on-site using machines or prefabricated in factories, independent of weather conditions, and transported to construction sites (Gelirli & Arpacıoğlu, 2022).

The "Roberta" machine, developed by Martin Rauch, is designed to make the production of compressed earth structures more efficient, durable, and scalable(Figure 9). It consists of four main components: the formwork system, material hopper, compaction unit, and cutting machine. With a semi-automatic mechanism, the forms are assembled and disassembled, while the unstabilized fresh earth mixture is evenly distributed into the mold. The compaction unit then compresses the material in layers, enabling the wall to reach the desired height (Gomaa, Schade, Bao & Xie, 2023) .

Figure 9. Roberta Machine (Gomaa et al., 2023).

Formearth, David Freeman’s company which develops compressed earth technologies, is working on a prototype automatic rammed earth machine. The system operates with an upward-moving panel formwork system. The earth mixture is automatically and evenly distributed into the machine via a wire-rope crane, eliminating manual transport and accelerating the process. Compaction is performed using a compactor similar to those employed in civil engineering applications. The prototype can produce a 2-meter-high wall within 50 minutes (Asal, 2021) (Figure 10).

Figure 10. Formearth's Prototype (Asal, 2021).

Recent studies have focused on production methods involving spraying techniques and robotic fabrication technologies. "Bioshotcrete" is a new technology aimed at spraying mortar onto preformed molds in the construction industry. In a study, clay-based mortar was applied onto a building envelope using the bio-spraying method deployed through drones (Šamec, Srivastava, & Chaltiel, 2019) (Figure 11).

Figure 11. Bio-Spraying of Mortar onto Building Envelope (Šamec, et al., 2019).

Another innovative spraying method is the shotcrete 3D printing technique. In this method, layers of earth are sprayed using a robotic arm to create a specific geometric shape (Schweiker et al., 2021)(Figure 12).

Figure 12. Spraying with Robotic Arm (Schweiker et al., 2021).

Modern digital fabrication methods for adobe structures enhance traditional earthen construction techniques by offering more efficient and creative solutions. Unlike manual traditional production, computer-controlled machines enable much faster and lower-cost manufacturing. Additionally, digital technologies allow for greater design flexibility, facilitating the creation of more functional and unique structures (Schweiker et al., 2021).

3. Innovative Adobe Buildings

In this section, innovative approaches to adobe materials are evaluated through modern adobe structures.

3.1. Examples of Adobe Material Innovation in Buildings

In a building constructed in Mexico in 2014 featured an 8-meter-high double adobe wall. The adobe mixture incorporated local soil with "bagazo," a waste material derived from agave fibers, aimed at increasing the binding capacity of the clay and preventing cracking (URL-1)(Figure 13).

Figure 13. Centinela Chapel (URL-2).

The Kampala residences, built in Uganda in 2022, utilized compressed earth bricks (Figure 14). These eco-blocks are made from a mixture of 90% local soil, 10% cement, lime, sand, and water. This material is a thermal and acoustic insulation that is more durable and sustainable than cement blocks and produces 30% less CO_2 emissions (Çamuşoğlu, 2022).

Figure 14. Kampala Housing Project (Çamuşoğlu, 2022).

3.2. Example of an Adobe Buildings Reinforced with Support Systems

In 2014, a church in Chile was restored using a rope mesh reinforcement system. This mesh was installed horizontally and vertically at intervals corresponding to the dimensions of the adobe bricks. This system was designed to prevent structural collapse during earthquakes. The low cost and easy accessibility of the rope offer significant advantages by improving structural behaviour and reducing the risk of collapse (Gribas, 2017) (Figure 15).

Figure 15. The Church Project (Gribas, 2017).

3.3. Adobe Structures Produced Using Innovative Systems

The Gaia project, located in Italy in 2018, is an example of sustainable architecture using locally sourced natural materials and agricultural by-products. The 3D printed material consists of 25% local soil, 40% straw, 25% rice husks, and 10% hydraulic lime (URL-2)(Figure 16).

Figure 16. Gaia Project (URL-2).

MuDD Architects created Terramia as a prototype for low-budget projects during Milan Design Week. Built on a bamboo frame, the structure was covered with a special fabric and a mud-fibre mixture was applied using a bio-spray method. Drone technology was employed to spray the insulating layer (URL-3, 2019) (Figure 17).

Figure 17. Terramia Prototype (Cano, 2022, URL-3).

The Alnatura Workswelt project in Germany covers an area of 13.500 m^2. A specially developed machine was used to perform the compaction operations. The building's prefabricated exterior walls, made of compressed earth, are three stories high and 12 meters tall. These walls are designed to support only their own load (Heringer, Blair Howe, & Rauch, 2019) (Figure 18).

Figure 18. Alnatura Arbeitswelt (Heringer et al., 2019).

4. Expert Insights on Adobe Materials and Applications

This section presents the findings from interviews conducted with five experts specializing in adobe materials and structures. The participants included four architects and one restorer. Three architects work in academia, one has experience in both academia and professional practice, and one is a full-time practitioner in the field.

The interview questions were designed to explore the current state of adobe buildings, their technical and social limitations, innovative approaches, and future potential from a multidimensional perspective. Interviews were conducted using pre-determined, fully structured questions, and participants were asked a total of 11 questions. Interviews were conducted both face-to-face and online, lasting approximately 1-2 hours. Data were collected via audio recordings.

Under the theme of the status and future of adobe materials in the construction sector, participants were first asked about the main obstacles hindering the widespread use of adobe in Türkiye. In this context, they identified several key barriers: the lack of technical knowledge, deficiencies in regulations and education, and negative socio-cultural perceptions. Secondly, they were asked about the reasons why adobe is not currently included as a load-bearing wall material in Türkiye’s earthquake regulations, and what technical improvements or regulatory adjustments would be necessary to overcome these limitations. The absence of adobe in the seismic code was attributed to a lack of standardization and insufficient experimental research. As potential solutions, participants emphasized the need for regulatory amendments, educational reforms, awareness-raising initiatives, and government-supported incentives. Finally, participants were questioned about the role public policies and regulations in promoting adobe use, and what type of incentive mechanisms or supportive policies could be effective. The participants highlighted that the process has begun with policy changes and the revision of regulations, stressing the importance of leadership by high-level institutions to promote sustainable and earthquake-resistant constructions. They noted that the use of such structures in public buildings and spaces, along with legislative and financial support in rural areas, would accelerate implementation. Additionally, it was expressed that interdisciplinary collaborations and increased R&D efforts are necessary to enable the effective use of adobe materials, in line with sustainability and modernization needs.

Under the theme of material performance improvement, participants were asked about the types of additives used to enhance the durability and resistance of adobe to water and compression, as well as the advantages of these additives in terms of performance and sustainability. While acknowledging that chemical additives, such as cement, can improve adobe's durability, participants emphasized their drawbacks—particularly regarding recyclability and environmental impact. They highlighted the necessity of adopting a balanced approach between environmental performance and structural durability when selecting additives.

Under the theme of the development of production processes from traditional to modern methods, participants were asked how traditional adobe production techniques have evolved under the influence of technology and how this transformation has affected the current usage potential of adobe materials. The participants noted that technological advancements have improved the speed, quality, and durability of adobe production; however, they also highlighted that high investment costs, lack of standardization, and infrastructural challenges hinder the widespread adoption of these developments.

Participants were further asked about the most significant factors to consider for the widespread dissemination of modern adobe production techniques. In this context, financial support mechanisms, interdisciplinary collaboration, and R&D efforts were emphasized as critical. Additionally, it was pointed out that new technologies provide cost advantages and labour efficiency, with potential to enhance sustainability and industrial production capacity. For the broader adoption of modern techniques, securing raw material supply, reducing costs, and gaining field experience were identified as essential.

Within the theme of social perception and awareness, participants were asked about the level of public awareness regarding modern applications of adobe, the reasons behind society's association of adobe with old, inadequate, and dilapidated structures, and how this perception could be transformed. Participants indicated that adobe buildings are generally viewed with a negative and outdated image. They attributed this perception to factors such as maintenance needs, hygiene concerns, and usability difficulties.

The second question under this theme focused on how the advantages and benefits of adobe can be more effectively communicated to the public. Participants stated that the negative perception of adobe can be transformed through modern applications, awareness-raising educational programs, and regulatory changes. Ensuring structural durability through proper technical applications and the implementation of visible, prestigious projects were highlighted as critical in changing social perceptions.

Additionally, it was emphasized that visual media, direct experience sharing, support from local governments, and community-involved projects play important roles in disseminating the benefits of adobe structures to society. The importance of written and visual materials for making information permanent was also underlined.

Under the theme of dissemination strategies and future vision, participants were asked about what measures could be taken to increase the use of adobe and expand its application within the modern construction sector. The participants emphasized that education, standardization, access to appropriate materials, technical development, and regulatory support are critical for the widespread adoption of adobe. It was noted that hands-on training, phased transition strategies, and certification documents ensuring reliability in the production process play a decisive role in gaining acceptance of the material in modern construction.

Furthermore, participants highlighted the need to develop technical applications, enhance visibility through prestigious projects, and support building standards and regulations to increase adobe usage in contemporary construction. They stressed the importance of promoting the advantages of adobe in terms of sustainability, energy efficiency, and construction techniques to a broader audience, as well as disseminating innovative approaches for its use in various building components.

5. Conclusion

Innovative approaches to improving the negative characteristics that limit the use of adobe include the development of adobe material composition, reinforcement with structural support systems, and the application of innovative production techniques.

Studies focusing on the improvement of adobe material composition have shown that reinforcing adobe with various additives positively affects properties such as durability, water resistance, and thermal insulation. However, differences in the methods employed, types of additives, and the evaluation criteria limit the comparability of results across studies. Therefore, new research conducted under varying conditions is necessary to deepen the existing findings.

Studies on strengthening adobe structures with structural support systems primarily aim to enhance earthquake resistance and prevent structural collapse. The results of these studies have demonstrated improvements in structural performance against seismic movements. These efforts are particularly significant for ensuring structural safety and preserving traditional buildings in low-income areas. However, most existing research has been conducted on small-scale specimens, and there is a need for experiments on full-scale samples to obtain more comprehensive and reliable results.

Studies examining innovative production techniques for adobe materials indicate that modern manufacturing methods make the process faster, more efficient, and less labour-intensive compared to traditional adobe construction techniques. However, for these methods to be widely adopted and integrated into the construction sector, technical details need to be clarified, and further experimental studies as well as large-scale application projects are required.

Recent projects demonstrate that adobe structures are still being produced and used worldwide; these projects incorporate more advanced material compositions than traditional adobe, innovative support elements, and modern production technologies. They result in faster construction and improve structural performance. The fact that research is conducted not only experimentally but also through practical applications on actual buildings indicates that developments in this field are finding real-world relevance.

As part of the national evaluation of innovative approaches to adobe materials, interviews were conducted with five experts, and the status of adobe in the construction sector, its challenges, and potential development areas were analysed thematically. The participants identified the primary factors limiting adobe use as the lack of regulations, negative social perceptions, insufficient education, and inadequate technical knowledge. They also emphasized that innovative additives for improving material performance, technological advancements in production processes, and social awareness initiatives play a critical role in expanding adobe usage.

With standardization, hands-on training, and regulatory support, adobe can become more visible in the contemporary construction sector and offer a strong alternative within the framework of sustainability.

In line with the findings and expert opinions obtained within the scope of the study, the following recommendations have been developed to ensure that adobe material can be used more widely and effectively in the construction sector:

Regulatory amendments and development of standards

- Legal gaps regarding the use of adobe as a load-bearing structural element in Türkiye limit the material's potential. It is important to update adobe construction standards and technical guidelines in the earthquake regulations to introduce clear and enforceable provisions for its use.
- New regulations should include detailed information on both material composition and construction methods to provide guidance for practitioners.

Educational reforms and development of technical knowledge

- Offering courses on ecological buildings and adobe materials in architecture and civil engineering departments, along with project-based learning, will help raise awareness among students.
- One of the most significant shortcomings in adobe production is the lack of skilled technical personnel and craftsmen familiar with its application. To contribute to increasing qualified human resources, organizing training programs that include up-to-date production methods for technical staff and craftsmen willing to specialize in this field would be effective.

Public policies and incentives

- Economic incentives such as tax reductions and low-interest loans should be provided for adobe producers and users.
- State-supported pilot projects in public spaces can be implemented to demonstrate the compatibility and structural potential of adobe buildings within contemporary architecture. These projects can directly show society that adobe offers a functional, aesthetic, and sustainable solution under current conditions, thereby accelerating the transformation of public perception about adobe.
- Adobe should be regarded as an environmental asset and integrated with rural development, local employment, and cultural heritage policies. The sustainability of adobe structures must be secured in the long term by preserving traditional knowledge and buildings, transferring this heritage to younger generations, and supporting local producers.

Social awareness and perception management

- To change the negative perception of adobe and raise public awareness, educational programs and wide-reaching information campaigns explaining the properties and potential of adobe will be effective dissemination strategies. Knowledge about adobe production and use should be conveyed to students through both technical and practical courses in schools. These practices can increase users' awareness and demand for adobe applications.
- Hands-on workshops for the public can demonstrate the ease of production, reduce prejudice as people physically interact with the material, and increase interest in production.

- Allowing the construction of modern, aesthetically pleasing adobe buildings adapted to contemporary needs in public and private spaces in Türkiye will help people better understand adobe's potential as they experience these environments.
- The benefits of adobe buildings and projects should be effectively communicated to the public through written and visual materials, social media, and public broadcasting channels.

Technological and production developments

- Research on the mechanical strength, environmental impact, and structural performance of adobe materials should be conducted through interdisciplinary approaches involving architecture, civil engineering, materials science, and environmental engineering. For this purpose, publicly funded R&D projects, university-industry collaborations, and technology development centers need to be encouraged.
- The supply processes for raw materials used in adobe production, such as soil, fibers, and stabilizers, should be optimized to reduce costs.
- Adobe should be reconsidered not only as a wall material but also as an interior partition, insulation element, or modular building component. Accordingly, innovative production techniques should be supported, and efforts should be made toward their standardization.

The reviewed studies and emerging technologies enable significant progress in overcoming adobe's limitations and demonstrate that its disadvantages can be improved. As a traditional and ecological building material, adobe is expected to have a broader application in the future as both an environmentally friendly and cost-effective construction material.

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Integrating Augmented Reality into the Design of Cultural Heritage Areas: A Comprehensive Approach for İstanbul's Historic Peninsula

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1. Introduction

Emerging digital technologies and mobile devices transform how users interact with urban space, generating new socio-spatial dynamics in behavioural patterns in the built environments. In line with this transformation, several studies point out that hybrid design practices in urban settings can enhance users' spatial experiences (Argin et al., 2019, 2020; Heinrich, Heitmayer, Smith & Zhang, 2025; Iavarone & Dursun Çebi, 2019; Iavarone & Dursun Çebi, 2022). With the advancement of digital technologies, augmented reality (AR) carries potential to produce cyber-physical experiences by overlaying digital layers into the physical environment (Ramtohul & Khedo, 2024; Ünal, 2013). This multilayered experience also creates new opportunities for walking and experimental route practices in historic urban environments, particularly through storytelling and raising awareness, as these areas serve as critical points for user interaction and the construction of spatial meaning.

Relatedly, in international literature, there are numerous studies associating AR with cultural heritage, but applications focusing on town-site experiences remain relatively limited compared to indoor settings such as museums and art galleries (Ramtohul & Khedo, 2024), since the issues such as maintaining the balance between screen-based and physical experiences in real environments still require further development. Particularly in Turkey, existing research predominantly concentrates on architectural visualization and modeling (Güleç Özer, Nagakura, & Vlavianos, 2016; Kozlu, Çoruh & Oke, 2021), but it is limited in terms of real user experiences and on-site interactive implementations.

Accordingly, this study aims to propose an AR-supported cultural route experience through designated mobile application interfaces related to the Historical Peninsula of Istanbul. In line with this objective, it discusses the relationship between spatial data and urban design, traditional tools and representational methods, as well as the theoretical framework surrounding experiential representations. It further explores the evolving behaviors of individuals in public space within an increasingly digital world, and defines the role of augmented reality (AR) in this context, and examined similar interfaces to inform design process (Figure 1).

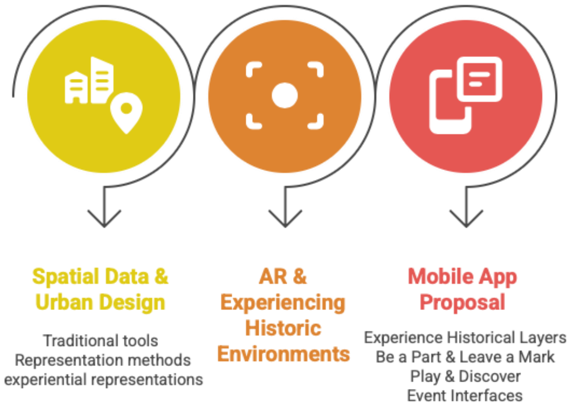

Figure 1. Structure of Research Flow.

Based on these, this research explores the potential of AR as a tool for engagement of pedestrians with historical layers of urban environments and seeks to answer the following questions:

- How can mobile augmented reality applications reshape users' engagement with cultural heritage in historic urban environments through spatial, perceptual, and behavioral dimensions?

- What types of spatial data, interface features, and experiential strategies are most effective in enhancing user interaction and heritage-based urban space?
- In the Istanbul Land Walls and the Historic Peninsula context, what spatial, functional, and participatory features should a mobile AR application incorporate to bridge historical narratives with present-day experiences and public use?

2. Traditional Methods in the Use of Spatial Data for Urban Design

The use of spatial data relies on mapping techniques, which serve as fundamental tools for understanding lived space and making predictions about its future. Mapping, which functions as both a language and a tool, provides a representational framework for data currently available at a specific time or planned for future use (Corner, 2011). Throughout history, spatial data has been used for a variety of purposes, including exploration, warfare, epidemics, agricultural or commercial efficiency, and urban problem-solving. As the objectives served by spatial information and their users have diversified, so too have visualization techniques and formats.

In contemporary usages, spatial data has moved beyond being a passive tool and has become an active component of the idea. Urban design is one of the areas where this transformation is most evident. The integration of spatial data with diverse layers of information, including social, environmental, and economic, has necessitated more sophisticated representation techniques, particularly in urban design (Kitchin, Dodge & Perkins, 2011). These techniques now play a crucial role in the design process by enabling the visualization of complex, multidimensional data. The development of digital technologies has significantly accelerated this evolution. The emergence and rapid advancement of two- and three-dimensional representation tools have increased the capacity to map not only physical environments but also lived experiences and daily urban practices.

2.1. Role of Spatial Data in Urban Design

Urban design is a multidisciplinary field, situated at the intersection of various design disciplines (architecture, urban planning, landscape architecture) and sociology, history, etc. It focuses specifically on the design of public spaces and their interaction with the built environment. Unlike many other spatial disciplines, urban design deals with a wide range of scales, including facades, streets, squares, urban green spaces, waterfronts, and neighborhoods.

The spatial data employed in urban design are not limited to physical or quantitative dimensions but often include qualitative and experiential components that reflect everyday life, social behaviors, and cultural practices. Because urban design often focuses on public spaces, it requires a deeper understanding of how spaces are used, perceived, and transformed over time. This has led to the increasing importance of spatial data not only as a descriptive or analytical tool, but also as a way to integrate human experience into the design process.

Moreover, spatial data in urban design serves as a medium through which problems are identified, interpreted, and addressed. It becomes part of the problem-solving mechanism itself, rather than a static background layer (Güleç, 2021). For example, mapping the usage patterns of a public square over time or analyzing pedestrian flows in a public space like a street are not merely descriptive studies but also a method of spatial reasoning. In this context, spatial data becomes an active design element that shapes the development of accessibility, inclusiveness, and environmental quality strategies.

As urban areas grow increasingly complex, the ability to integrate various types of spatial data—ranging from GIS layers to participatory mapping and sensory data—becomes ever more critical. Urban designers must engage with data that are dynamic, multi-scalar, and embedded with social meaning. Therefore, the role of spatial data in urban design transcends its traditional instrumental function and is redefined as a core component of creative and context-sensitive design processes.

2.2. Traditional Data Sources and Tools

In urban design, spatial data sources have long served as foundational references for understanding the physical, social, and functional structures of a given area. They can generally be grouped into four main categories: physical representations of the natural environment, spatial reflections of the human-made environment, historical records as manifestations of urban memory, and representations of socio-spatial experiences.

Maps containing natural space data provide crucial information about the natural physical environment, including terrain slope, elevation, water resources, soil structure, geology, and natural thresholds. Such data is particularly valuable in understanding the relationship between urban settlements and the natural landscape and in making informed decisions for sustainable design. In this context, the morphological evolution of natural structures and the transformation of the environment over time can be effectively interpreted through traditional tools. On the other hand, cadastre, zoning plans, aerial photographs, and archival records—each representing different aspects of the human-built environment—are among the most frequently used traditional spatial data sources. Cadastre informations, often utilized in the planning process, present parcel-level data on property ownership, building typologies, and boundary conditions. Zoning plans, in turn, define building rights and the designated uses of public and private spaces. Aerial photographs enable comparative analysis of the urban fabric across different time periods, thus making spatial change processes observable and traceable. Moreover, archival documents and historical maps are also considered critical components of traditional spatial data. These sources provide insights into the historical development of a city or region, property relations, urban memory sites, and collective identity. The value of such documents is significantly heightened considering cultural and social dimensions of urban space.

Despite their importance, the representational formats offered by traditional data sources and tools are often limited. They tend to be one-dimensional, static, and detached from real-time user experience. As a result, they fall short in capturing the complexities and dynamic nature of contemporary urban environments. This limitation has triggered the emergence and necessity of next-generation data collection and representation methods, including more interactive, digital, and participatory approaches that align better with the evolving needs of urban design.

2.3. Representation Techniques

When discussing traditional representational techniques, maps, plans, sections, elevations, and three-dimensional models stand out as fundamental tools. These tools are initially used to analyze existing conditions and, as ideas emerge throughout the process, to transfer them to the spatial plane. Two-dimensional plans and maps are particularly effective in demonstrating horizontal organization and functional relationships within space, while sections and elevations help illustrate the vertical dimensions and proportions of buildings and how they interact with their surroundings. While these traditional techniques have strengthened the comprehensibility and visual communication of urban design, they have remained limited in conveying experiential, perceptual, and temporal dimensions; expressing the experiential qualities of space, user movements, or transformations occurring over time.

On the other hand, three-dimensional representation techniques provide a more realistic presentation of the volumetric and physical qualities of urban space in design projects. Further beyond that, user-centered data representation plays a critical role in making visible the individual experiences and perceptions related to public spaces, which are essential to socio-spatial representation in urban design. Methods such as annotated maps, spatially-referenced survey data, experience maps, and user profiles enhance the inclusivity and participatory nature of the design process. In this way, not only the physical space but also its social and emotional layers are incorporated into the design framework.

2.4. Experiential Representations

Beyond traditional spatial representations, there are experimental and experience-based mapping approaches. While conventional maps mostly focus on representing the measurable and objective features of physical space, creative maps are alternative forms of representation produced by current or past users of a space. They aim to reveal the experiential and perceptual dimensions of space or to foresee desired experiences. These forms of mapping, which have become increasingly prominent in architecture and urban design, consider not only what a space is but also how users feel, live, and conceptualize that space (Güleç, 2021). In this context, creative maps go beyond being merely tools of representation and become instruments of design practice. These types of maps, which enable reading the multilayered structure of the city through individual or collective experiences, correspond to the spatial data of participatory representation.

One of the most prominent types in this mapping approach is mental maps. These maps are drawn based on personal experiences such as how individuals perceive, remember, and navigate a place. They reflect subjective orientations and sensory memories in the city. This technique gained prominence with Lynch's studies on the image of the city (Lynch, 2014). Another form of creative mapping is narrative maps. These maps are based on the spatial representation of specific storylines, social narratives, or personal histories. These narratives often include individual's relationship with space is not only physical but also mental and emotional.

Additionally, interactional maps have emerged as prominent forms of representation through digital technologies. These are spatial representations shaped by real-time experiences of individuals or communities and are redefined according to momentary interactions. Open to user participation, providing instant data flow, and often multilayered, these maps function not only as a means of display but also as part of the design process. With the help of mobile devices, augmented reality, and web-based mapping tools, user experience can become a larger part of design. Thus, creative maps can become not only narrative or representational tools, but also participatory and interactive design tools. They can also become part of participatory decision-making processes.

3. Integrated Use of Spatial Data: The Role of Augmented Reality in Historic Environments

3.1. Pedestrian Behaviors in the Digital Age and Toward a Need for Hybrid Space

Developing information and communication technologies (ICT) and digital devices (smartphone, smartwatches, tablets etc.) have significantly influenced daily human life, reshaping forms of socio-spatial interaction. In this context, new dynamics have emerged in the behavioral patterns of individuals and groups within physical space. Alongside the increasing use of smartphones, there has been a growing body of research focusing on mobile users in public spaces. These studies reveal that smartphones—depending on usage patterns—affect social interaction (Humphreys & Hardeman, 2020), lead to shifts in attention during activities in physical space (Alsaleh, Sayed & Zaki, 2018), and alter walking behaviors by influencing speed, decisiveness, and spatial perception (Lamberg & Muratori, 2012).

Accordingly, some studies examining how technology influences human behavior emphasizes the significance of spatial hybridization in urban settings and the emergence of the "post-flâneur" (Argin et al., 2019; Iavarone & Dursun Çebi, 2022). Upon closer examination, there are studies highlighting the distancing effect of smartphones from physical space, others point out that depending on the usage type—such as taking photos or recording videos—smartphones may actually increase the duration of public space use and foster new forms of spatial engagement. Based on these studies, users who are more disconnected from their surroundings and experience a fear of missing out, engaging in virtual interactions while walking, may be referred to as “smartphone zombies” (Appel, Krisch, Stein & Weber, 2019; Argin et al., 2020). In contrast, those who interact with space through mobile devices and experience a simultaneous cyber-physical engagement are considered as “post-flaneurs” (Argin et al., 2019; Iavarone & Dursun Çebi, 2022). The reflections of these interactions on urban space can manifest in a variety of forms, ranging from minimal to more advanced: signals, electronic texts, smart urban furniture, QR codes, interactive projections, responsive façades, and more (Argin et al., 2020).

In this context, AR applications can be regarded as a potential technology that allows individuals to experience an enhanced, cyber-physical interaction by superimposing a digital layer onto the physical environment while they continue to engage with it (Azuma, 1997; Graziano & Privitera, 2020). Particularly, the integration of AR with various devices—within the scope of this study, a mobile application downloadable to smartphones is proposed—and systems positions it advantageously in terms of enabling interaction and enriching the perception of real-life. Accordingly, the following sections will focus on the potentials of this technology and its modes of implementation in urban space more particularly on heritage sites.

3.2. AR and Its Potential for Experiencing Historic Environments

In its broadest sense, augmented reality (AR) enhances the real world by overlaying virtual objects via computer-generated data—such as visuals, models, animations, audio, or video (Çalışkan & Sevim, 2021; Pandey Pandey, Mahajan, Paul & Iyer, 2024; Ünal & Demir, 2018; Van Krevelen & Poelman, 2010). While various sensory-based techniques exist, current applications predominantly focus on visual perception (Ünal, 2013, p. 5).

Milgram & Kishino (1994) well-known model defines a continuum of mixed reality, encompassing both Augmented Reality (AR) and Augmented Virtuality (AV), in which the real and virtual worlds are blended. In this context, AR functions as a tool for aligning digital information with the real world and has a wide range of applications across diverse fields such as industry, medical sector, tourism(Çalışkan & Sevim, 2021), education, retail and advertising sectors, 3D reconstructions, location based-data representation(Ünal & Demir, 2018), entertainment and gaming and so on (Azuma, 1997; Pandey et al., 2024; Van Krevelen & Poelman, 2010).

Typically, AR hardware consists of a camera, processor, and display devices such as head-mounted displays, handheld devices (e.g., smartphones or tablets), spatial projectors (e.g., holograms), or screen-based displays (2D). With the rise in smartphone usage since the 2000s, AR has become accessible even to users with limited technological literacy, expanding its potential for broader public engagement (Ünal, 2013). Related to these developments, AR has evolved beyond laboratory environments to utilize a variety of handheld and mobile platforms, allowing digital and hybrid experiences to be embedded in urban contexts(Van Krevelen & Poelman, 2010).

On the other hand, even though significant improvements, AR still faces some limitations. For instance, constructing a dataset for urban environments for complex tasks requires attention to data privacy, classification, data management, and real-time processing. Also, there are some types of displays that, considering their low brightness, contrast, and resolution may not be suitable for outdoor use; calibration issues may occur; creation of depth perception could be challenging and mismatch location-objects (Van Krevelen & Poelman, 2010). Therefore, to make location-based AR experiences meaningful in urban space, systems must respond integratively to the physical environment and operate as part of users' spatial perception. Furthermore, using AR-based gaming applications such as Pokémon GO may result in pedestrian safety issues in urban environments (Chen, Saleh & Pai, 2018), so applications in real environments must consider both digital content, physical reality, environmental factors, and user behaviors.

Applications of AR in the built environment include purposes such as data visualization, historical reconstructions, wayfinding and navigation, spatial guidance, geotagging, cultural interpretation, on-site training, supporting community participation. In cultural heritage contexts, AR is primarily used for heritage site management, and conservation, preservation, bringing to life past events; and trending application topics in that manner can be list as reconstruction of cultural artifacts, digital heritage, virtual museums, education, tourism, intangible cultural heritage, and gamification (Boboc, Băutu, Gîrbacia, Popovici & Popovici, 2022). One of its advantages is the ability to represent historic places, buildings, and values within their original temporal contexts, revealing invisible or intangible features to users. Additionally, interactive information gathering during site visits supports location-based learning of cultural heritage assets.

Relatedly, AR has become a popular tool in museums due to their controlled environments, and ease of object recognition. Museums adopt such applications to provide visitors with beyond-the-glass experiences (e.g, British Museum, Acropolis Museum). Mobile-based AR applications allow users to engage with exhibitions without special hardware, which is an advantage for institutions, and it makes a scalable and user-centered approach (Angelopoulou et al., 2012). Besides indoor uses, numerous mobile AR applications have also been developed to enhance tourism-oriented heritage experiences (Çalışkan & Sevim, 2021).

AR usage in cultural heritage provides a unique tool for integrating 3D historical visualizations with heritage sites and architectural landmarks, and this offers innovative methods for shaping public experiences of urban environments. Moreover, it serves as a medium for communicating architectural and cultural heritage—often inadequately conveyed by traditional preservation and interpretation methods—to wider audiences (Amakawa & Westin, 2018).

Accordingly, AR-based approaches need advanced technological, spatial, and experiential integration in historical areas. Apart from indoor settings of AR-based heritage mobile applications, outdoor urban zones contain more complex and uncontrollable dynamics, so related apps must consider accurate geolocation, robust object recognition, and seamless spatial registration to align virtual content while using location-specific storytelling, interactive visualizations, and context-aware strategies. Especially, gamified user interfaces can increase engagement, enhance experiential depth, and extend the meaning of physical surroundings (Angelopoulou et al., 2012), as long as pedestrian safety is carefully considered. In this regard, mobile AR interfaces have the great potential to transition from supplementary interpretive tools to central mediators of the lived heritage experience in contemporary urban contexts.

3.3. Heritage Meets AR: Lessons from Global Examples

Since this chapter proposes the development of an AR-based mobile application, this section reviews exemplary mobile AR applications implemented in outdoor and heritage contexts. Case studies such as Vitica Application, DinofelisAR, CityView AR, and Xeros River Valley Project are examined in terms of their project background, application domains, utilized spatial data, and the user experiences, as summarized below.

Vítica Application is an augmented reality–based mobile app developed as part of a project aimed at reactivating the cultural heritage of Medellín's Cisneros Square and its surroundings (Hincapié et al., 2021). The application operates in domains such as cultural heritage and tourism, on-site education and experiential learning, and pedestrian-oriented exploration in public spaces. Its spatial data include GPS-based points of interest, temporal layers representing historical events and actors, and multimedia elements such as photographs, texts, audio recordings, and 3D AR models. The user experience is structured around a spatial narrative that integrates AR content during the walking tour, including the *plaza's historical milestones, significant events and actors, legal documents, and their corresponding dates*. In the study, control and experimental groups were compared in terms of cultural heritage learning, and users of the application achieved significantly higher levels of historical knowledge and spatial understanding (Hincapié et al., 2021, pp. 3–7).

CityViewAR is a mobile AR application that visualizes Christchurch's urban landscape before and after the devastating 2011 earthquake. The project aims to support post-disaster recovery by reconstructing the city's place-based memory and historic sites (Lee, Dunser, Kim & Billinghurst, 2012). CityViewAR operates across domains such as digital reconstruction of built environment, urban planning, visual storytelling and educational outreach. Users can explore the former *cityscape through location-based AR content, including map views, 3D models of buildings, historical photographs, and metadata*. However, technical challenges such as limited tracking accuracy, alignment issues, and outdoor lighting conditions were noted (Lee et al., 2012, pp. 58–63).

DinofelisAR is a mobile AR prototype developed to enhance the cultural heritage experience at the Roman Ruins of Conimbriga. It was tested in 2017 at the open-air archaeological site of the Conimbriga Monographic Museum (Marto, Gonçalves & de Sousa, 2019). Operating across cultural heritage interpretation, tourism, and the application allowed users to explore a 360° virtual reconstruction of the Forum overlayered on existing ruins. The spatial data relied on a marker-based AR system using Vuforia SDK with Extended Tracking, which enabled the virtual content to remain aligned with the real-world remains even when the marker moved out of view, while the 3D spatial model depicted the Forum's columns, walls, and temple. Participants reported that the application made the visit more dynamic and enjoyable, was easy to use, and increased their interest in downloading and using similar AR applications in the future(Marto et al., 2019, pp. 83–89).

The AR-based Cultural Route at the Xeros River Valley (Cyprus) was developed to enhance the exploration of the region's archaeological and sacred landscapes. The application is a part of a project UnSaLa-CY, and serves as an interactive cultural route integrating tourism, informal learning (Ioannou, Lanitis, Vionis, Papantoniou & Savvides, 2021). Target images are placed at key points of interest to trigger informational content, while selected sites feature GPS-based 3D reconstructions of medieval settlements and early Byzantine architecture. The spatial data contains 360° panoramic images, historical photographs, textual narratives, and 3D models. The gamified model boosts visitors' ability to complete the route by scanning targets, earning points, and interacting with multimedia content, similar to a treasure-hunt-like experience (Ioannou et al., 2021, pp. 698–701).

4. A Mobile AR Concept for Istanbul Historical Peninsula and Land Walls

4.1. General Information about Site and Urban Design Competition

The study area is the Topkapı Kaleici Square of the Istanbul Land Walls and the urban design competition held there in 2022. This area holds significant historical importance as it marks the entrance to the Historic Peninsula through the Land Walls (Figure 2). In addition to serving as a key connection point between two major urban arteries—Vatan Avenue and Millet Avenue—it is located at the intersection of the M1 Yenikapı–Atatürk Airport Metro Line, the T1 Kabataş–Bağcılar Tram Line, and the Metrobus Line. Due to its function as a major public transport stop, the square has been identified by the local municipality as a problem area. In response, an urban design competition was initiated to restore the square to its former historical and cultural significance within the collective memory of the Historical Peninsula (Söylemez, Dinemiş Aman & Salihoğlu, 2023). Once a symbolic beginning and end point in the historical settlement structure of the peninsula, the square gradually lost this importance as Istanbul expanded and grew. Despite being part of a layered historical and cultural system, it has become disconnected from the city's public space network.

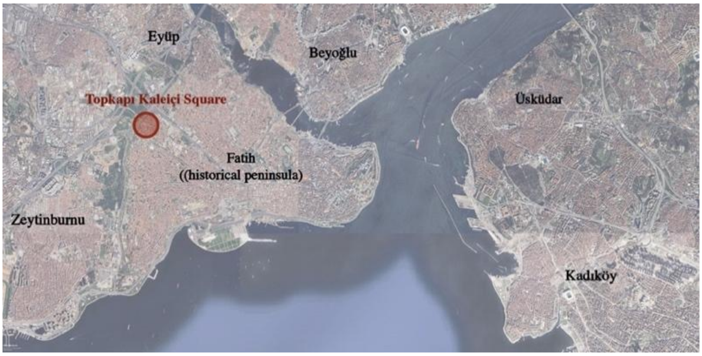

Figure 2. Historical Peninsula and Location of Urban Design Competition.

The competition was launched with a multi-scalar approach, seeking design solutions not only for the square itself but also for the historical peninsula and its regional context. Expectations were high that the proposed square would be reintegrated into the urban and public systems, and this context became the focus of the competition. The local government encouraged the integration of the site's existing values into open and public spaces, both at the scale of Istanbul and within the Historical Peninsula.

In this context, the design proposal that was submitted to the competition and awarded first prize—also the subject of this research—adopted a hybrid methodological approach, utilizing both traditional and innovative spatial data at square and regional scales. Drawing on a "palimpsest" approach, the proposal aimed to integrate spatial data from different historical periods into the contemporary urban experience (Karakoç, 2022). Beyond conventional two- and three-dimensional mapping techniques, the project also employed information and communication technologies to explore ideas for interactive spatial use. Through the application of AR, it sought to strengthen the integration between the square and the Historical Peninsula (Figure 3).

Figure 3. Narrative Zones for Interactive Spatial Experiences (Karakoç, 2022).

4.2. AR-Based Mobil Application Proposal

Contemporary technologies are transforming users' everyday experiences, reconfiguring our relationship with the city and our behavioural patterns in urban space through the simultaneous use of physical and virtual environments. In this context, innovative hybrid design strategies are gaining increasing popularity. **"Topkapı: A Historic City Experience"** is a mobile application proposal that aims to adapt augmented reality and gamification approaches to engage users with the multilayered history of Istanbul's Land Walls and the Historical Peninsula. The application proposal uses digital interfaces to foreground tangible and intangible heritage to the surface in public space. Through this tool, walking experiences in the historic environment are transformed into historical journeys, allowing users to access traces of the past both in situ and digitally, supported by physical urban furniture and signage placed along the route (Figure 4).

Figure 4. General Interfaces for Proposed Mobile App.

Experience Historical Layers: The application proposal includes predefined routes across the Istanbul Land Walls and the Historic Peninsula [e.g., *Sur Boyu* (along the land walls) and *Sur Yolu (on the land walls*)]. At selected points along these routes, the aim is to convey historical authenticity to the user by presenting photographs and illustrations from various periods—including the Byzantine Empire, Ottoman Empire, Early Republican era, and the present day. Through digital interfaces and the identification of physical objects in the environment, users can access comprehensive information on the current urban space via their mobile devices and view representations of urban space from different historical periods in an integrated manner. This enhances the depth and richness of the route experience (Figure 5).

Regarding spatial data usage, the historical visual materials and layered information provided at these points will be curated using spatial data sets, archival documents, and narrative maps that connect the city’s temporal transformations with user experiences.

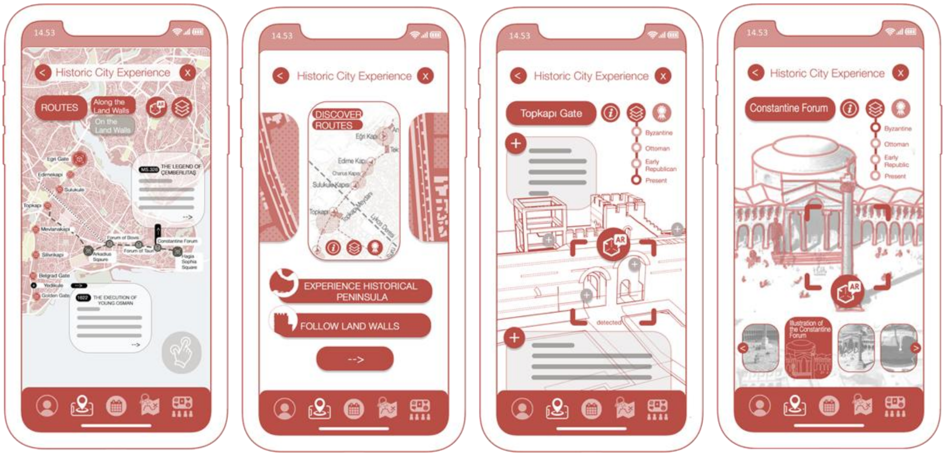

Figure 5. Interface Proposals for AR-based Historical Layer Experience.

Be a Part & Leave a Mark: These interfaces enable users to provide feedback on the urban space, share their route experiences, and interact with other users. Users can submit geo-tagged feedback linked to their real-time location through the application interface, allowing comments to be recorded as spatial annotations. As the number of contributions increases, spatial hotspots emerge based on user density and comment frequency. Popular user-generated content is highlighted depending on interaction levels and visibility within the interface. Additionally, these tools allow stakeholders to initiate site management and activity programming discussions. The proposed platform transforms collective feedback into dynamic layers that can be visualized, archived, and utilized in future decision-making processes for site governance and adaptive spatial interventions via interactive mapping tools and location-based user inputs.

Play & Discover: The Play & Discover interfaces aim to create the route experience into a city-based game, making the act of heritage exploration playful. The system, which progresses as users collect clues across different categories, motivates users to become part of the city's history and culture. Clues positioned along the Sur Boyu and Sur Yolu routes are designed to direct users to the next stop, the clue system is structured around experiential and interactional maps. Users can scan these clues via mobile devices, they earn points, and subsequently, these points can potentially be redeemed for tickets or discount coupons to museums around Topkapi, participation rights in limited-capacity Kaleici Square activities, or guided tours during festivals and biennials. When users complete different routes or participate in site-related activities constantly, they can attain statuses such as "traveler," "urban explorer," or "discoverer,". (Figure 6).

Figure 6. For In-Situ Experiences; Participatory and Playful Interfaces.

Event Interfaces: These interfaces help users stay informed about events in Topkapı Kaleiçi Square and around the Land Walls, track ongoing activities, and propose new events. Users can easily add events to their monthly calendars, receive notifications about the events they follow, submit their own event proposals to the relevant authorities, and request support for the spatial needs of these proposals (Figure 7).

Collecting event-based data and their registered participants and frequencies can support decision-making mechanisms related to the temporary design and event-based management of public squares and routes.

Figure 7. Proposals for Event-based Interactive Usage of Public Space.

4.3. Exploratory Spatial Use Scenarios

The mobile application proposal is structured around four key functions: experiencing historical layers, interacting with and marking the land walls, playful engagement within the Historic Peninsula, and event-based usage of public spaces. As outlined in the urban design competition framework, spatial strategies aimed to reconnect the Land Walls with the lost traces of the Historic Peninsula through two main systems: along-the-land-walls and on-the-land-walls routes. Key locations identified in Figure 3 are designated as focal points for embedding digital layers. In particular, forums and squares that still retain partial physical traces in the urban fabric—but whose heritage visibility has diminished due to the complexity of contemporary urban space—are planned as AR-based narrative zones to restore their historical significance. Accordingly, this chapter has developed four distinct collages reflecting possible user experiences on-site to anticipate potential spatial dynamics.

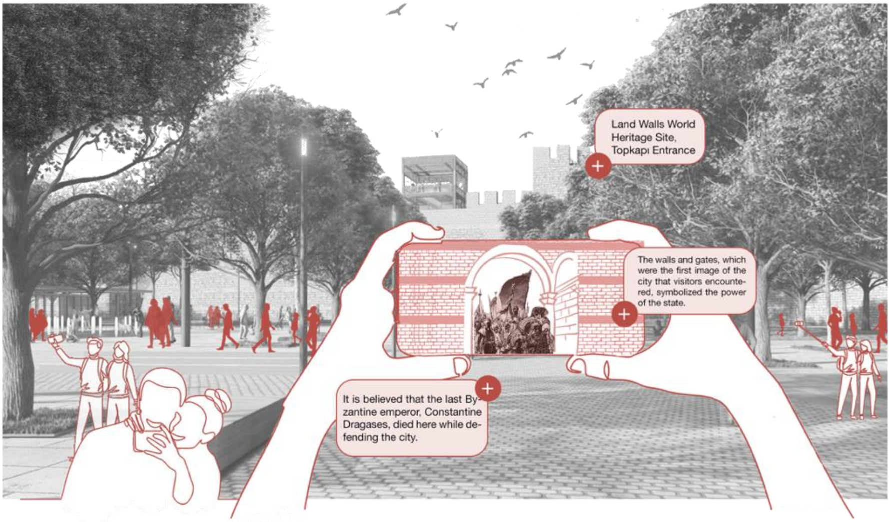

Figure 8. Conceptual image of Topkapı/Kaleici Square and Land Walls.

The urban design project aims to transform a symbolically significant segments of the Istanbul Land Walls into a pedestrian-oriented cultural experience such as Topkapi -an area historically associated with the 1453 Conquest (Figure 8). Spatial data will include georeferenced points along the Land Walls and square, layered historical content narrating episodes from the conquest, multimedia elements such as historical texts, visuals, and animated reconstructions of historical events.

Another featured landmark along the proposed AR-based cultural route is the former site of the Forum of Theodosius (Figure 9), which once featured monumental structures such as the Column of Theodosius and the

Triumphal Arch of Theodosius. Today, only limited physical remnants of these elements remain visible (Ateş, 2025). The project aims to digitally reconstruct the arch's historical appearance by anchoring AR content to existing existing on-site columns. Thereby restoring the visibility of these lost urban forms digitally. This approach may be enhanced by integrating 3D historical models and augmented heritage narratives in Beyazit.

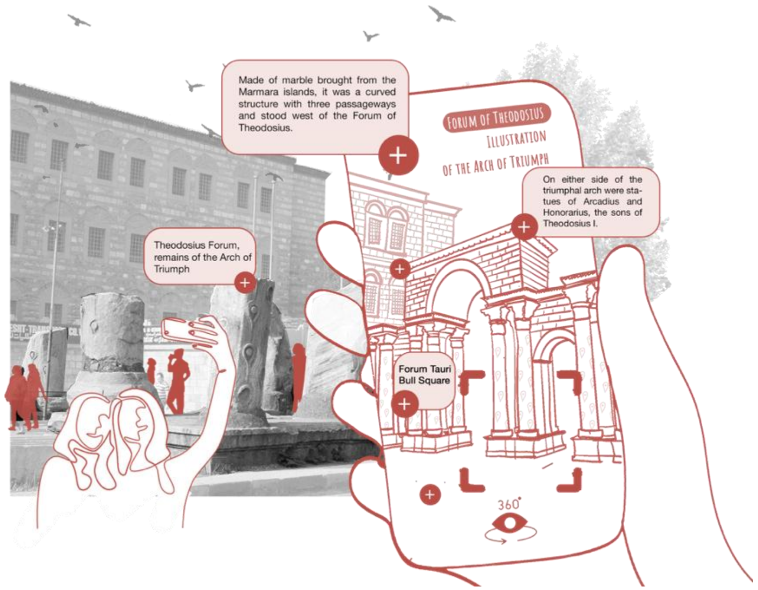

Figure 9. Conceptual image of Forum of Theodosius.

An additional experimental stop within the AR-based cultural route is the Porta Aurea, or Golden Gate, which historically served as the ceremonial entrance to the Theodosian Land Walls (Figure 10). Known for its role in imperial triumphal processions during the Byzantine period (Asutay-Effenberger, n.d.). Although several transformations occurred, the surviving architectural fragments still reflect the spatial importance of the gate regarding the urban landscape. With the integration of AR content to existing remains and georeferenced access points, this project will provide interactive experiences due to the spatial data, such as 3D reconstructions, historical illustrations, and narrative texts This will allow users to experience the architectural evolution and ceremonial functions of the gate in situ, effectively bridging tangible and intangible aspects of cultural heritage.

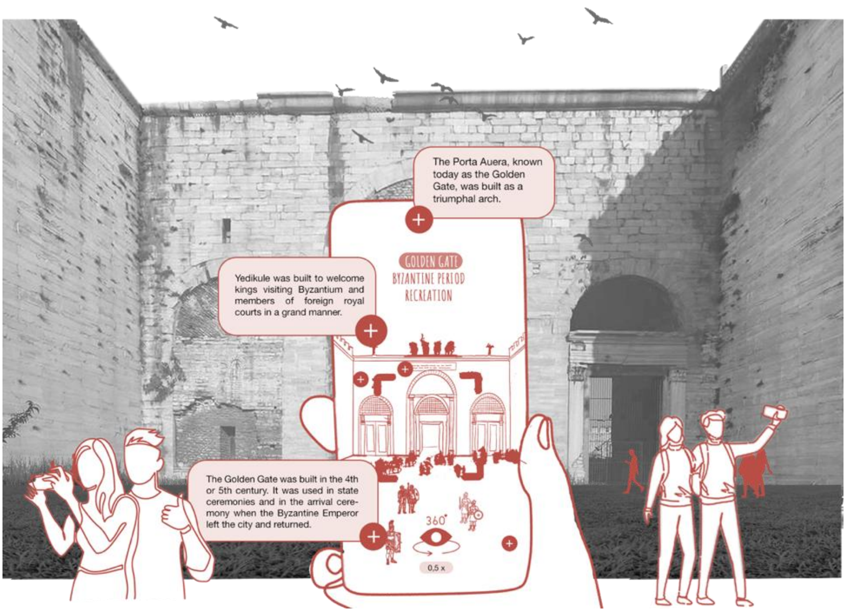

Figure 10. Conceptual image of Golden Gate.

The Forum of Constantine, the imperial forum of the city, is another key site within the proposed AR-based cultural route. The Forum of Constantine was designed as a major public space considered the center of the city. At the heart of the forum, a monumental column was erected with a grand ceremony. This column is known today as Çemberlitaş (Ulutürk, 2010). At its top originally stood a bronze statue of Apollo. The AR interface aims to visualize the column's symbolic and architectural evolution across historical periods through temporally layered content to bridging urban memory (Figure 11).

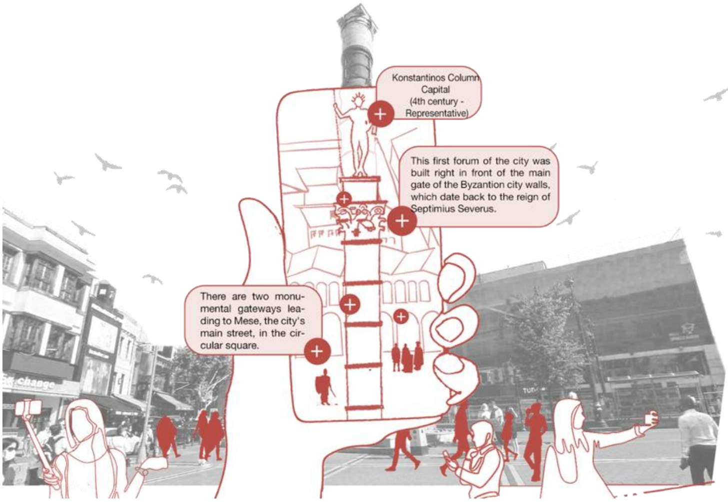

Figure 11. Conceptual Illustration from Forum of Constantine.

5. Conclusion and Suggestions

Within the scope of this research, a route-based experience is proposed that integrates digital and physical layers in the urban environment to enable users to perceive the historic context beyond its visible features. Based on the conceptual framework, case studies, and preliminary design proposal, the key findings can be summarized as follows:

- One of the most important advantages offered by AR is that spatial data transforms into digital data and then into an experience, becoming a part of the design.
- The obvious demonstration of the AR technologies' potential is the use and evaluation of natural, human and historical data (from different periods) as part of the instantaneous experience, while producing new spatial data.
- AR mobile application offers significant opportunities to evaluate different layers of spatial structure together beyond traditional mapping methods.

- The use of AR mobile applications not as standalone tools but as integrated components of urban experiences enhance user engagement in cultural and heritage sites of cities.
- Digital layers hold considerable potential for uncovering historical urban strata and conveying past experiences and narratives. Experiences facilitated through handheld mobile devices offer ease of use and accessibility, thereby appealing to broader user groups.
- AR, particularly through gamification techniques, can increase the younger generation's interest in historic environments and foster cultural heritage awareness. Such approaches encourage users to learn through play and to experience urban history through interaction.
- Mobile AR experiences are directly linked not only to digital design elements but also to spatial positioning and users' perceptual scale of the environment.
- Although AR presents certain technical limitations, it holds significant potential for hybrid space design and experiential planning. When integrated with site management strategies in historic environments, AR can go beyond visualization to also support public participation and heritage governance processes.
- On the other hand, the use of AR in heritage-related contexts in Turkey remains relatively limited. Most existing projects and proposals tend to remain at the level of architectural visualization. Consequently, the behavioural impact of such interventions on users within actual urban space remains underexplored—largely due to the limitations of previous studies and the lack of simultaneous, real-life implementations.

Despite offering a conceptual framework, the study remains at a speculative level without real-life user testing or system prototyping. The AR application is presented hypothetically, limiting its validation in actual urban contexts. Future research should prioritize empirical implementation, user behavior analysis, and integration of spatial data infrastructures to test the efficacy of AR-based heritage experiences in dynamic, open-air environments.

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Author Contributions and Conflict of Interest Declaration

This book chapter was co-authored by two authors who contributed equally to the work, and there are no conflicts of interest to declare.

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A Critique of the Redevelopment of the Golden Horn Shipyard and Coastline Based on the Example of the Boston Naval Shipyard

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1. Introduction

Shipyards have historically functioned not only as centers of naval and commercial production but also as symbols of technological progress, state power, and urban identity. From antiquity to the industrial era, the establishment of shipyards has reflected both geopolitical necessities and the pursuit of maritime dominance. Their foundation processes often coincided with critical stages of national development, where the mastery of shipbuilding and repair was directly associated with military strength and international trade. In this context, shipyards such as the Boston Navy Yard in the United States and the Golden Horn (Haliç) Shipyards in Istanbul represent two different yet comparable trajectories of industrial heritage shaped by their respective cultural, political, and economic environments.

The Boston Navy Yard, founded in 1800, was among the first federal shipyards in the United States and became a model of modern shipbuilding during the 19th and 20th centuries. It not only supported the American Navy in major conflicts but also pioneered industrial innovations that influenced civilian sectors. Its transformation after closure into a cultural and historical landmark illustrates how adaptive reuse can successfully preserve industrial heritage while ensuring public accessibility and urban integration. For this reason, Boston has been selected as a reference point in this study to evaluate how inclusive planning, functional zoning, and public participation can contribute to sustainable heritage management.

From the outset, it is equally crucial to highlight that this study does not solely focus on Boston. The Golden Horn Shipyards—dating back to the Ottoman Empire and continuing their significance throughout the

Republican era—form the other pillar of the comparative analysis. The Haliç shipyards, once capable of producing fleets that symbolized the power of the empire, have undergone profound changes in recent decades through processes of privatization, deindustrialization, and transformation into cultural and commercial facilities. Their inclusion from the beginning ensures that the scope of the paper equally reflects both international and local dimensions of industrial heritage.

The main purpose of this paper is to critically compare the adaptive reuse of the Boston Navy Yard and the Golden Horn Shipyards in order to identify the principles of industrial heritage conservation that can guide future redevelopment projects. By analyzing the socio-cultural and physical transformations of both sites, the study aims to demonstrate how historical continuity, public engagement, and balanced urban programming can determine the success or failure of shipyard regeneration projects. The findings are expected to contribute not only to academic discussions but also to policy frameworks that emphasize culturally sensitive and community-oriented approaches in the field of industrial heritage.

Boston Navy Yard

Established in the early 19th century as one of the first federal shipyards in the United States, the Boston Navy Yard played a crucial role in the expansion and modernization of the U.S. Navy. Throughout history, it was actively utilized in major conflicts such as the American Revolution, the War of 1812, and both World Wars. It also served as a center for the construction and repair of some of the oldest and most renowned warships in U.S. history, including the USS Constitution. In this context, the shipyard stands as a prominent symbol in the maritime history of the United States**.**

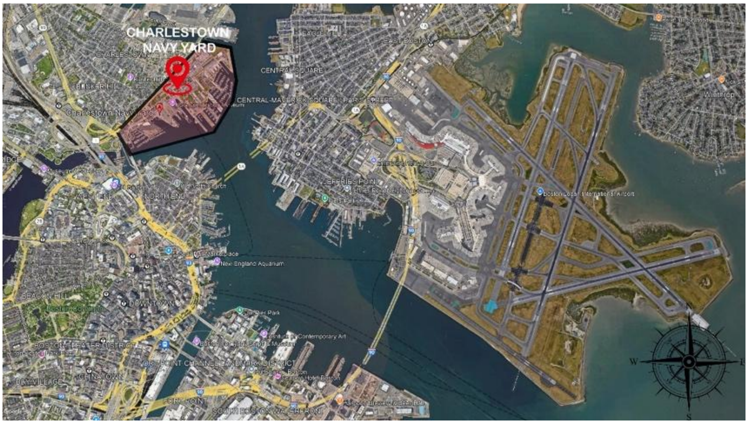

Figure 1. Map Showing the Geographical Location of the Boston Navy Yard (Googleearth).

The geographical location of the Boston Navy Yard made it a strategic base on the East Coast (Figure 1). Its proximity to the Atlantic Ocean rendered it a vital point for both defense and logistical operations. This strategic positioning elevated the yard's importance not only for military purposes but also in terms of national security and commercial maritime activities. The yard is also renowned for its contributions to industry and technology. Since the 19th century, it has been at the forefront of advanced shipbuilding technologies, playing an active role in the production of various innovations—from the earliest steam-powered vessels to modern steel warships. During the Industrial Revolution, the yard served as a crucial platform not only for military production but also for the advancement of civilian industry. Additionally, it helped anchor maritime culture within society, fostering its transmission across generations.

For many years, the Boston Navy Yard provided employment opportunities to the city and surrounding region, contributing significantly to the local economy and encouraging the development of regional maritime and shipbuilding industries. Following its closure, the Boston Navy Yard was recognized as an industrial heritage site and placed under preservation. The restoration of its structures and their conversion into museum spaces have reinforced its cultural significance. Today, the Boston Navy Yard stands as a major site of industrial heritage and an important cultural landmark that reflects the historical identity of Boston. With its rich history, it offers visitors a tangible connection to the past, while increasingly serving as a prominent tourist attraction at both the local and national levels.

1.1. History of the Boston Navy Yard: Foundation and Origins

The Boston Navy Yard was established in June 1800 by the Massachusetts Legislature in honor of the 25th anniversary of the Battle of Bunker Hill (Gordon, 1999). Initiated by Secretary of the Navy Benjamin Stoddert, land was acquired in the Charlestown area, where a shipyard was constructed and official operations commenced. On May 9, President John Adams approved the site of the Boston Navy Yard in Charlestown, and construction began shortly thereafter (Carlson, 2010). The primary objective behind the establishment of the yard was to strengthen the naval forces of the United States and to gain a competitive edge in the maritime race with European powers.

Considering the technological advancements in shipbuilding during the 19th century, the Boston Navy Yard emerged as a center of innovation, particularly in the construction and repair of steam-powered vessels. Shipbuilding activities began in 1813; however, in 1826, a 2,400-foot (730-meter) granite wall was constructed, effectively separating the yard from the rest of Charlestown (Gordon, 1999). In 1814, construction began on the USS *Independence*, the first ship built at the yard. As the first large vessel produced at the Boston Navy Yard, the *Independence* served as a testament to the shipyard's manufacturing and technological capabilities. This marked the transformation of the yard into a fully recognized center for ship construction and repair. With the laying of its keel in May 1814, the *USS Independence* became the first ship launched from the yard (Carlson, 2010).

In 1828, engineer Colonel Loammi Baldwin developed the most effective layout for the Navy Yard, featuring rectangular buildings arranged along five streets (Gordon, 1999). Alexander Parris, one of Boston's most prominent architects, designed many significant structures for the facility (Gordon, 1999). The construction of the dry dock, initiated in 1833, further enhanced the yard's technological capabilities. The building of Dry Dock 1 began on June 1 under the supervision of Chief Engineer Loammi Baldwin (Carlson, 2010). During this period, the yard gained attention not only for ship production but also for various industrial activities conducted on-site. The completion of the dry dock provided a significant advantage in the maintenance and repair of steam-powered vessels. During the American Civil War, the yard became one of the most critical bases supporting the Union Navy. Employment peaked at 4,955 during the war, reflecting the high demands placed on the facility (Carlson, 2010). This period saw a notable increase in both the workforce and the yard's production capacity.

In the 20th century, the Boston Navy Yard played an active role in both World War I and World War II, standing out for its modernization of warships and its capacity for rapid and large-scale production. However, in the post-war period, the yard's strategic importance gradually declined, leading to its closure in 1974 (Carlson, 2010) (Figure 2). This development brought forth discussions about preserving the site as part of the nation's industrial heritage.

Figure 2. Aerial Photograph of the Boston Navy Yard in 1974 (Gordon, 1999).

1.2. Adaptive Reuse of the Boston Navy Yard

The architecture of the yard is characterized by red brick and granite structures. Colonel Loammi Baldwin, one of the most influential figures in the engineering and architectural circles of the period, made significant efforts to ensure the yard's orderly and systematic construction. Among the historic buildings is a wooden structure dating back to 1813, recognized as America's first official "shipyard." Additionally, structures such as the ropewalk and large 19th-century industrial buildings reflect the functionality and durability of industrial architecture (Figures 3–4).

Figure 3. Preserved Industrial Heritage Structures in the Navy Yard (Mcgavern, 1994).

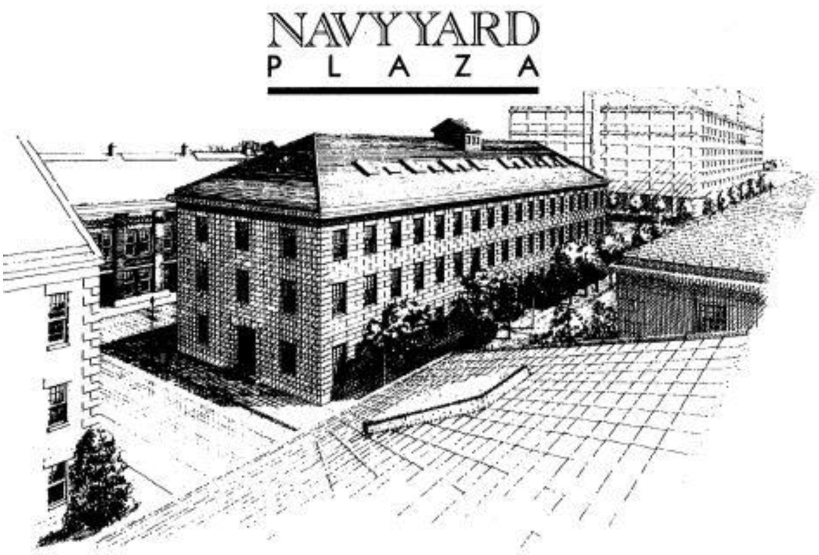

Figure 4. Cooper Building (Building 38), Repurposed from Warehouse to Office Space (Gordon, 1999).

Also known as the Charlestown Navy Yard, the Boston Navy Yard played a significant industrial and military role in American maritime history from 1800 to 1974. Over its 174 years of service, it implemented various technological and logistical innovations to meet the needs of the U.S. Navy through shipbuilding, repair, and modernization. From a military standpoint, the Boston Navy Yard served as a key logistical and production hub, enhancing the Navy's operational capabilities at sea. During the Civil War, the yard played a critical role in the rapid conversion and preparation of warships. In World War I, it converted captured German vessels into troop transports and repaired over 450 ships. During World War II, the yard reached its peak production capacity, employing over 50,000 workers. Throughout this period, the shipyard expanded its workforce to include individuals from diverse ethnic backgrounds, reflecting broader social inclusion. During the Cold War, the yard continued to support military innovation by modernizing destroyers and integrating new missile systems.

The Boston Navy Yard was not only a center for shipbuilding and maintenance but also a symbol of innovation in American maritime history. Due to its industrial power and military-strategic importance, it became an indispensable facility in both wartime and peacetime. By adapting the yard for contemporary use, designers emphasized its historical significance, ensuring the transmission of its legacy to future generations and reinforcing its place in the collective memory of the city and the nation. Today, this historic site is preserved as part of the Boston National Historical Park.

Post-closure redevelopment plans focused on preserving the site's historical features while integrating new uses. The Boston Redevelopment Authority (BRA) acquired much of the site, which included designated areas for public parks, historic buildings, and new development. This adaptive reuse approach encouraged a vibrant mix of residential, commercial, and cultural activities, transforming the Navy Yard into a vital component of Boston's urban and maritime heritage.

- Historic and Cultural Sites: A portion of the Navy Yard is managed by the National Park Service and is home to historic vessels, including the *USS Constitution* (Old Ironsides)—the oldest commissioned warship still afloat in the U.S. Navy, dating back to World War II—and the destroyer *USS Cassin Young*. In addition to parks and commemorative elements, the site features museums. The *USS Constitution Museum* offers interactive exhibits and educational programs focused on maritime history and shipbuilding.
- Residential and Commercial Development: Many historic buildings, including former military warehouses and workshops, have been converted into residential apartments, offices, and research facilities. For instance, building 114 has been transformed into the Massachusetts General Hospital Biomedical Research Center, while other structures have been repurposed for mixed-use developments.
- Public Spaces and Recreation: A waterfront promenade has been designed to ensure public access to the shoreline, linking different parts of the shipyard and offering views of the harbor. Surrounding the walking paths, large open spaces with playgrounds and seating areas have been created to attract both residents and visitors.

- Education and Innovation: Organizations such as *Courageous Sailing* have developed educational programs, particularly for youth, focused on sailing and environmental stewardship.
- Commercial and Dining Options: The area's appeal to tourists has been enhanced with waterfront restaurants and cafés, contributing to the vibrant atmosphere of the redeveloped site.

The Navy Yard is divided into four main zones: (1) the National Historic Park Area, (2) the Historic Monument Area, (3) the New Development Area, and (4) the Public Park Area (Figure 5).

- *National Historic Park (NHP):* A 30-acre area managed by the National Park Service. It includes historic ships and buildings, as well as museums and educational facilities.
- *Historic Monument Area (HMA):* This 31-acre zone contains structures of high historical significance, notably the ropewalk and other former workshops.
- *New Development Area (NDA):* Spanning 58 hectares, this area includes not only preserved historic buildings but also modern residential and commercial developments.
- *Special Public Park Area (SP):* Originally established as a 16-acre zone, it features the wharf, dry dock, and shipbuilding areas.

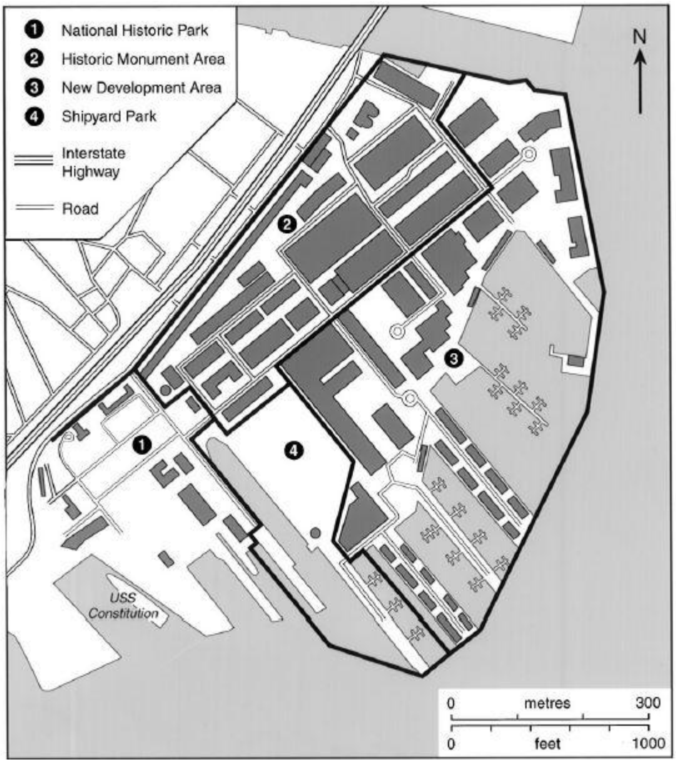

Figure 5. Map Showing the Areas of the Boston Navy Yard Following Restoration and Adaptive Reuse (Gordon, 1999).

The Navy Yard has been listed on the National Register of Historic Places in a manner that ensures the preservation of its original structures. However, these buildings have been restored and adapted for modern use. While adapting historic buildings to contemporary functions, preservation efforts are guided by regulations that maintain the site's historical character. The designation of the Navy Yard as a National Historic Landmark has reinforced the continuity of conservation efforts.

The harbor has been expanded and improved to ensure public access and to transform the waterfront into a public promenade and viewing area. In line with accessibility principles, signage and informational panels have been installed to help visitors understand the site's historical evolution. In the revitalized area, modern residential and commercial buildings have been constructed and integrated into the historic landscape. Former shipbuilding piers and dry docks have been repurposed into recreational boating and tourism facilities (Figure 6).

Figure 6. Photographs of the Current State of the Charlestown Navy Yard from Multiple Perspectives (Google Earth).

Most of the industrial buildings within the Navy Yard have been repurposed into functional spaces while preserving their historical appearance. The Charlestown Navy Yard has become a major cultural and tourism hub, offering visitors an immersive experience in maritime and industrial history. The *USS Constitution*, the world's oldest commissioned warship still afloat, is the centerpiece of the Navy Yard and is open to public tours. The *USS Cassin Young*, a Fletcher-class destroyer from World War II, serves as a floating museum showcasing advancements in naval technology.

To honor the technological progress achieved during its operational years—such as the production of anchor chains and innovations in steel shipbuilding—Dry Dock 1 and the Chain Forge workshop have been converted into multifunctional spaces that blend industrial heritage with craft-focused events and programming. The *USS Constitution Museum* features interactive exhibits, including hands-on experiences such as knot-tying and historical reenactments that bring maritime history to life.

The museum and adjacent park area also host an education center that offers maritime history courses. The yard supports educational programs for schools and families, providing insights into shipbuilding, marine life, and heritage conservation. The museum’s restoration exhibit highlights ongoing efforts to preserve the historic ship, further enhancing its cultural significance.

The redevelopment balances public access, residential use, and historical integrity. The integration of the harbor walk supports modern urban activity while providing a recreational and educational path that connects visitors to the preserved industrial past of the Navy Yard. The site plan shown in Figure 7 illustrates key spatial elements, including decision points, nodes, access points, and continuous circulation routes that have shaped the area’s development. Through adaptive reuse, historic preservation, and educational initiatives, the site’s legacy remains an integral part of Boston’s urban and cultural identity.

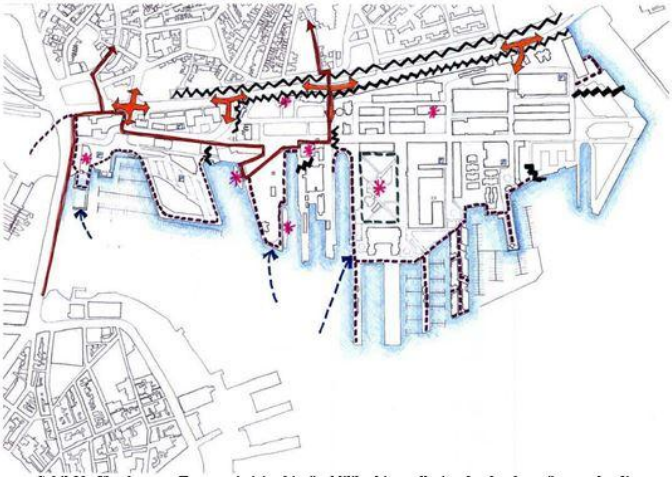

Figure 7. Diagram Illustrating the Barriers and Discontinuities at the Entrance and within the Circulation of the Charlestown Navy Yard (Mccann, 2007).

The participation of the public, as much as that of various disciplines, has been a key reason for selecting this group of structures as a case study in this publication. As mentioned by McCann (2007), in developing the MHP Amendment to the Harborpark Municipal Harbor Plan for the Charlestown Navy Yard's "Double Interpretive Loop Plan", the BRA has coordinated with State and City officials and with the Municipal Harbor Plan Advisory Committee ("MHPAC") which includes representatives from harbor advocacy groups, residents, elected officials, business people, business and real estate associations, and other interested parties. The BRA held two meetings with the MHPAC to the discuss the MHP Amendment. The BRA also held three community meetings in coordination with the Charlestown Neighborhood Council as well as a community workshop/charrette. Additionally, the BRA has presented findings to the Charlestown Municipal Harbor Plan Advisory Committee, the Boston Harbor Association Harbor Use Committee, National Park Service, Courageous Sailing program, CNY residents and businesses (McCann, 2007).

2. Material and Method

This study employs a comparative case study methodology to critically examine the adaptive reuse processes of historical shipyards, with a particular focus on the Boston Navy Yard and the Golden Horn (Haliç) Shipyards in Istanbul. The research integrates historical analysis, spatial observation, and policy review to explore how industrial heritage sites are reprogrammed for contemporary urban functions, while assessing the role of public participation and cultural continuity in these transformations.

The Boston Navy Yard serves as the primary reference model due to its internationally recognized heritage preservation strategy, public engagement practices, and successful integration of historical structures into the urban fabric. The site was examined through secondary sources including archival records, academic publications, and official planning documents from the Boston Redevelopment Authority and the National Park Service. Special attention was given to its functional zoning, architectural interventions, and social programming that facilitated its transformation from an industrial facility to a cultural, educational, and recreational space.

For the Golden Horn Shipyards, the research draws on local planning documents, government reports, and scholarly critiques to evaluate the post-industrial trajectory of Istanbul's waterfront. Visual data such as site plans and photographs were utilized to understand the spatial consequences of policy decisions and architectural interventions. The study also considers participatory frameworks—highlighting the contrast between the inclusive planning model of Boston and the more top-down transformation observed in Haliç.

Through a cross-analysis of both sites, the study aims to identify the key factors that contribute to sustainable, culturally sensitive, and publicly supported adaptive reuse practices. The methodology emphasizes qualitative evaluation, critical reading of spatial policies, and synthesis of architectural and social outcomes to provide a grounded and transferable framework for future redevelopment of disused ports and shipyards, particularly within Türkiye.

3. Findings and Discussion

3.1. Revitalization of the Golden Horn Waterfront and Adaptive Reuse of the Golden Horn Shipyards

Significant shipyards during the Ottoman Empire included those in İzmit, Karamürsel, Gallipoli, Istanbul, Sinop, and Suez. The first major and organized Ottoman shipyard was the Gallipoli Shipyard, whose construction began in 1390 during the reign of Yıldırım Bayezid. Until the establishment of the *Tersane-i Amire*, this shipyard served as the most important naval base of the empire. Founded by Sultan Mehmed the Conqueror in 1455, the Golden Horn Shipyard became one of the largest shipyards in the world during the 16th century, with a capacity to build up to 249 ships in a single year. Another major shipyard of the era was the *Tersane-i Amire*, also known as the Galata–Golden Horn–Istanbul Shipyard, which remained the central base of the Ottoman Navy until the fall of the empire (UAB, 2025).

Following the proclamation of the Republic, war-torn Türkiye required capital to support its development and modernization efforts. The early

Republican government believed that this capital could be generated primarily through the utilization of the country's natural and mineral resources and by expanding export opportunities. As a result, attention was directed toward ports and piers, which served as gateways for goods to reach international markets. To stimulate maritime trade and revitalize the economy, legal regulations concerning ports and piers were introduced as an initial step. Subsequently, in 1925, ports and piers that had previously been under foreign control were transferred to Turkish joint-stock companies established with domestic capital, with tariffs set and regulated by the government. Additionally, efforts were made to classify port operations as public services (Yurtoğlu, 2019).

During the Republican era, efforts were made to address the technological and infrastructural deficiencies of shipyards, and necessary investments were initiated. In this context, by 1935, military shipyards had reached the capacity to construct submarines. In 1938, plans were made to build one shipyard capable of constructing vessels up to 5,000 tons and two additional shipyards capable of simultaneously building four ships of up to 1,000 tons each. Recognizing the future importance of commercial vessels, construction work began in 1939 on the Pendik Shipyard in Istanbul. Subsequently, the capacities of the Camialtı Shipyard (1965) and the Gölcük Shipyard (1966) were expanded. In 1970, the Tuzla Shipbuilding Industrial Zone was established. According to the Ministry of Transport and Infrastructure (UAB), the number of shipyards increased by 127%, rising from 37 in 2003 to 84 by 2021 (UAB, 2025).

Due to its historical development, geopolitical location, function as a natural harbor, favorable climate conditions, and proximity to industrial and commercial centers, the Golden Horn holds significant importance (Figure 8).

Şekil 8. İstanbul Haliç, Camialtı and Taşkızak Shipyards (Yerliyurt, 2008).

Despite unregulated alterations, adverse user interventions, and a rapid period of decline, the Istanbul shipyards continued to function without losing their overall form until the late 20th century. However, beginning in the late 20th century, policies involving privatization and closure placed the future of these shipyards—whose history spans over five and a half centuries—at serious risk (Köksal, 2005). The Haliç and Camialtı Shipyards were included in the scope of privatization in 1993 and, in 1995, the shipyard area was designated as a protected site by the Istanbul No. 1 Board for the Protection of Cultural and Natural Heritage.

In 2000, during the ANASOL-M coalition government, the High Council of Privatization (ÖYK) ordered the closure of the shipyards. As a result of this decision, 1,100 employees lost their jobs (Şener, 2000). The decision to close the shipyards was primarily based on the objective of deindustrializing the Golden Horn area and cleaning the sea water and surrounding environment of industrial waste. In the Environmental Master Plan prepared in 2006, Istanbul was approached with an emphasis on global competitiveness and branding potential. The plan highlighted that the adaptive reuse of disused and idle industrial structures, as well as the existing stock of historic buildings in the Golden Horn, would offer opportunities for the development of cultural industries (İBB, 2006). Under the section titled "Culture, Tourism, and Service-Oriented Projects," the report identified the "Golden Horn Tourism Zone" as the most significant initiative.

As outlined in the Environmental Master Plan report, it was envisioned that the 16-kilometer-long shoreline would be transformed into a "cultural corridor" through the development of museums and cultural centers. In line with this vision, a protocol signed between the Istanbul Metropolitan Municipality and the Naval Forces Command led to the transfer of ownership of the shipyards in the Golden Horn to the municipality (İBB, 2006). This development removed one of the most significant legal and ownership barriers to the transformation of the shipyards (Şen & Sarıca, 2024). The shipyards located along the Golden Horn—an area dense with industrial heritage—were subsequently excluded from protection status and designated as a "special project area." In 2011, the Ministry of Environment and Urbanization announced the project titled "Golden Horn Marina and Complex Project," widely known to the public as Haliçport (İpek & Balyemez, 2019). It is useful to consider both the positive and negative aspects of these developments:

Pros:

- Revitalizing the waterfront with cultural, touristic, and public functions can stimulate economic and social activity in the region.

- The transfer of property ownership reduces bureaucratic barriers, potentially accelerating the transformation process.
- Converting the shipyards into touristic and cultural facilities may help transmit industrial heritage to future generations.

Cons:

- Removing protection status from the area increases the risk of damage to the historical fabric.
- Declaring the area a "special project zone" may prioritize commercial interests over the public good.
- If the physical presence of industrial heritage is not preserved and only represented symbolically, it may result in a weak model for cultural continuity.

Today, the Golden Horn is characterized as a fluid and undefined zone, described by Şen & Sarıca (2024) as *"Haliç Fantasies."* The area is marked by a lack of programmatic direction, with interventions implemented without a coherent scenario or narrative. Although the initial goal was to align the site with the cultural and creative industries, the space has instead become one where all kinds of unrelated activities are permitted, leading to a condition of programmatic ambiguity.

Currently, the Camialtı and Taşkızak shipyards have been incorporated into the *Tersane Istanbul* project, while part of the Haliç Shipyard, under the administration of the Istanbul Metropolitan Municipality's City Lines, has been converted into the Istanbul Museum of Art (Figure 9).

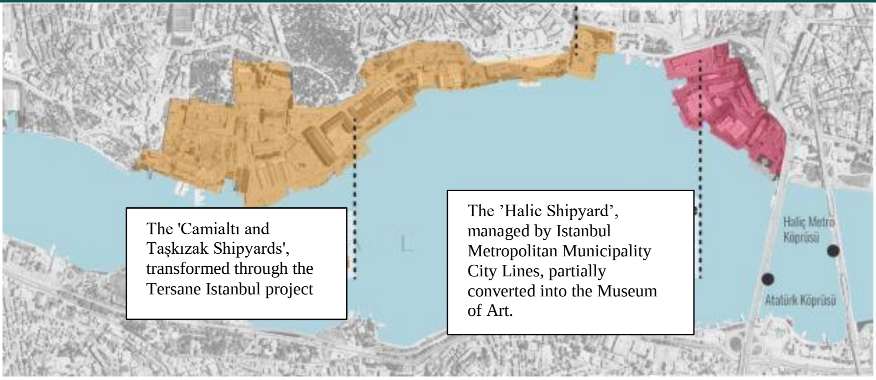

Figure 9. Map showing the Haliç Shipyard, Camialtı, and Taşkızak Shipyards (Bianet, 2025).

3.2. Comparative Analysis

The Boston Navy Yard and the Golden Horn Shipyard both stand as historically significant maritime centers, yet their development paths differ considerably. The Boston Navy Yard, deeply rooted in the United States' naval history, evolved from an industrial and military hub into a fully restored cultural and touristic site. Its architecture reflects post-Industrial Revolution construction techniques, and today the area functions as a museum and recreational space. In contrast, the Golden Horn Shipyard embodies the Ottoman Empire's naval heritage and continues to hold symbolic value in Istanbul's collective memory. Divided into Camialtı, Taşkızak, and other zones, it combines Ottoman and Republican-era architecture, with ongoing restoration projects that aim to balance preservation and adaptive reuse (Table 1).

Table 1. The comparison of Boston Navy Yard and Golden Horn Shipyard.

Criteria	Boston Navy Yard	Golden Horn Shipyard
Socio-cultural	One of the first major naval centers of the United States. The resident population mainly consisted of naval personnel and industrial workers. Surrounding neighborhoods developed as working-class districts.	The heart of Ottoman naval culture. Surrounding neighborhoods (Kasımpaşa, Hasköy) were shaped by artisans, craftsmen, and laborers. Holds a deep-rooted place in the socio-cultural memory of Istanbul.
Physical Arrangements	During modernization, the shipyard was divided into 4 main zones (shipyard buildings, administrative areas, museum, and park). Comprehensive restoration and reorganization projects led to its adaptive reuse.	The area is divided into Camialtı, Taşkızak, and Golden Horn Shipyard. Parts have been transformed into the Istanbul Art Museum and Tersane Istanbul projects. Restoration and redevelopment are still ongoing.
Architectural Design	Structures built after the Industrial Revolution with brick, iron, and timber techniques. Preserved buildings have been repurposed as museums and cultural facilities.	Ottoman-era stone and timber constructions, combined with Republican-era industrial buildings. Some structures have been restored and converted into new functions (museum, hotel, cultural venues).
Environmental Changes	Transitioned from an industrial harbor to a cultural-touristic center. Today, the waterfront serves urban recreation and tourism.	Transition from industrial use to cultural and touristic functions. Golden Horn revitalized through water purification and coastal redevelopment projects.

The Boston Navy Yard's main advantage lies in its successful preservation and transformation into a cultural and touristic destination, although this process has limited its role in providing economic opportunities for the local community. Conversely, the Golden Horn Shipyard retains elements of its original production functions and benefits from its central location in Istanbul, giving it a strong link to historical continuity. However, it faces challenges such as incomplete restoration, intense tourism and real-estate pressures, and tensions between protecting urban memory and accommodating contemporary development needs (Table 2).

Table 2. The Advantages and Disadvantages.

Site	Advantages	Disadvantages
Boston Navy Yard	Successfully preserved, fully converted into museums and cultural sites, and functions as a touristic attraction. Contributes to the urban economy through culture and tourism.	Lost its industrial role, now limited to cultural and touristic uses. Provides relatively limited direct economic benefits for the local community.
Golden Horn Shipyard	Strong historical continuity, representing Ottoman maritime heritage up to the present day. Some production functions still remain. Central location in Istanbul offers spatial and cultural advantages.	Restoration and transformation processes are incomplete. Subject to intense tourism and real-estate pressure. Conflicts arise between preserving urban memory and current redevelopment uses.

4. Conclusion and Suggestions

This paper underlines the principles of industrial cultural heritage, such as preservation of authenticity, adaptive reuse, integration with the urban fabric, and the transmission of collective memory to future generations. By comparing the Boston Navy Yard and the Golden Horn Shipyard through these principles, it becomes evident that while the Boston case demonstrates a completed process of conservation and transformation into a cultural-touristic asset, the Golden Horn represents an ongoing struggle to reconcile preservation with contemporary urban pressures. This comparison highlights both the universal values of industrial heritage and the locally specific challenges that shape the future of historic shipyards.

While deindustrialization as a general policy may be a justifiable approach for the transformation of the Golden Horn region, the resulting programmatic void presents significant challenges. The lack of a cohesive program has led to interventions that are disconnected at the urban scale—some of which even disrupt pedestrian circulation. New functions, introduced without a clear spatial needs and capacity analysis, often appear mismatched to their context. Volumetrically oversized additions and, most critically, the absence of public participation have hindered the successful adaptation of historical buildings along the Golden Horn waterfront. These issues raise questions about whether such redevelopments are truly embraced and owned by the urban community.

According to Şen & Sarıca (2024), the Golden Horn Shipyards continue to be a matter of public debate, oscillating between dichotomies such as "production or service?" and "public interest or corporate interest?" As Kuyumcu (2020) also notes, the dominant narratives of inevitability—those that justify benefiting a small, globally connected, high-skilled elite and real estate speculators at the expense of widespread displacement through gentrification—are increasingly being questioned.

Today, the Golden Horn Shipyard has been reopened for public use under the name Istanbul Sanat by the Istanbul Metropolitan Municipality's IBB Miras (IBB Heritage) initiative. Information about the site's adaptive reuse is available on the İBB Miras official website (Figure 10).

> *'The Haliç Shipyard continues its operations today by preserving its historical legacy and remaining faithful to its traditional roles in shipbuilding and repair. These dual operational branches serve the maritime industry. With the opening of the entrance hangars to the public, the shipyard area has become accessible to visitors, offering opportunities to host various events for both residents and tourists. Within the scope of the Haliç Shipyard Cultural Structures project, the restored hangars have been reprogrammed to accommodate art and cultural activities. The interior spaces of the*

hangars have been designed to support artistic and performance-based uses. These flexible, multi-purpose interiors provide suitable environments for exhibitions, concerts, theatrical performances, dance shows, and other cultural events. Furthermore, the design of these interiors prioritizes accessibility and user experience, offering visitors a welcoming and engaging atmosphere' (İBB Miras, 2025).

Figure 10. Interior Photographs Showing the Current Use of the Haliç Shipyard, Restored by İBB Miras and Reintroduced to Istanbul Under the Name "Istanbul Sanat" (İBB Miras, 2025).

In the design and programming process of adaptive reuse projects, as seen in the example of the Boston Navy Yard—where the involvement of the public played a crucial role—the appropriation and long-term acceptance of new functions by local communities is a primary condition for the sustained success of such transformations. For structures, harbors, and open spaces belonging to decommissioned shipyards, public engagement ensures that these spaces are embraced and maintained over time, thereby extending their functional lifespan and architectural endurance.

In this regard, identifying community needs and including the public in the decision-making process is of great importance. Although this study focuses primarily on the critique of the Haliç Shipyard, it is worth noting that many unused ports exist along the Black Sea and Aegean coasts. The structures and facilities associated with these ports remain standing today. Based on occasional news reports, there have been periodic proposals for their adaptive reuse, though many of these plans have remained unfulfilled promises. Only a few ports have actually been restored and reintegrated into urban life.

Therefore, any future efforts to repurpose such port facilities must be approached with care and sensitivity, learning from past mistakes to ensure more sustainable and publicly supported outcomes.

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This book chapter complies with national and international research and publication ethics. Ethics committee approval was not required for this study.

Author Contributions and Conflict of Interest Declaration

This book chapter was written by a single author, and there are no conflicts of interest to declare.

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Assessment of the Potential Use of Native Wild Plum (*Prunus* spp.) Species from the Van Region in Sustainable Landscape Architecture

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1. Introduction

The environmental crises faced by the 21st century have emerged not only as primary concerns for the natural sciences but also for spatial planning and design disciplines. Global-scale phenomena such as climate change, biodiversity loss, soil erosion, depletion of water resources, and rapid urbanization are significantly impacting all systems involving nature–human interactions. These processes pose threats not only to ecological systems but also to human health, psychosocial well-being, and the quality of spatial environments (Tzoulas et al., 2007; Gómez-Baggethun & Barton, 2013). It is now widely acknowledged in scientific circles that cities must be designed not merely as human settlements but as vital systems in which ecosystem functions are sustainably maintained and regenerated (Bolund & Hunhammar, 1999; Hirons & Sjöman, 2019).

Within this context, the discipline of landscape architecture stands out as one of the most critical fields where environmental sustainability intersects with spatial design. The planning of urban green spaces has transcended its traditional role of serving aesthetic purposes and has evolved into a strategic tool that delivers multi-layered ecosystem services, fosters climate resilience, and offers nature-based solutions (Tzoulas et al., 2007; Gómez-Baggethun & Barton, 2013). At the heart of this transformation lies the selection of plant materials. Particularly in addressing issues such as the urban heat island effect, air and water pollution, noise, habitat loss, and ecosystem fragmentation—problems exacerbated by urbanization—the appropriate choice of plant species plays a crucial role (Bolund & Hunhammar, 1999; Chaparro & Terradas, 2009). In this regard, native (autochthonous) plant species are gaining increasing importance due to their ecological functionality and contributions to sustainable landscape design.

Plants offer a wide range of ecosystem services, including carbon sequestration, soil stabilization, water filtration, air purification, microclimate regulation, and habitat provision for wildlife (Nowak, 1994; Bolund & Hunhammar, 1999). These services go beyond direct environmental benefits; they also contribute to human health, enhance aesthetic perception, and nourish cultural identity through layered and interrelated values (Chiesura, 2004; Gowdy, Howarth & Tisdell, 2010). However, the continuity of these benefits is directly linked to the selection of appropriate plant species. One of the key advantages of native species is their natural adaptation to local climatic conditions, soil structures, and environmental stress factors (Van Huylenbroeck, 2018). This adaptation reduces maintenance needs, lowers irrigation demands, and contributes to the long-term sustainability of landscapes.

The use of native species is important not only for ecological sustainability but also for cultural continuity. Landscape is increasingly viewed as a medium that reflects the historical memory, local knowledge, and identity of societies (Karlović, Radočaj & Pluščec, 2022). Indigenous flora constitutes a natural extension of this memory. Traditional uses, folk medicine, local cuisines, and aesthetic preferences have been largely shaped by these plant species. Therefore, incorporating native species into landscape design serves as both an environmental and socio-cultural act of restoration.

The Eastern Anatolia Region, particularly the province of Van, is one of Turkey's richest areas in terms of floristic diversity and holds significant potential in this respect. Due to its varied altitudes, geological diversity, and microclimatic zones, the Lake Van basin hosts a wide range of endemic and native plant species. Among these, certain wild plum species belonging to the genus *Prunus* stand out. In particular, species such as *Prunus spinosa* L., *Prunus divaricata* Ledeb., and *Prunus* × *domestica* L. are notable native species with high ornamental value and resilience to environmental conditions, making them suitable for use in sustainable landscape planning (Alp, 2019).

The genus *Prunus*, a member of the Rosaceae family, encompasses a wide morphological range—from fruit trees to shrubs, and from dwarf forms to ornamental plants. This diversity offers considerable opportunities both in terms of agricultural production and landscape design (Sjöman, Hirons & Bassuk, 2017). *Prunus* species provide seasonal visual continuity in urban and rural landscapes, with their early spring blossoms, summer fruit production, and autumn foliage coloration. Additionally, they make significant contributions to ecological cycles by offering food and shelter for wildlife (Hirons & Sjöman, 2019).

One of the most striking features of *Prunus* species indigenous to the Van region is their high resistance to low precipitation regimes and poor soil conditions. This trait provides a substantial advantage for sustainable landscape design in semi-arid and mountainous areas. Furthermore, these species can function effectively as windbreaks, boundary elements, and natural hedges. Their contributions to preventing soil erosion, enhancing water retention capacity, and strengthening habitat connectivity further highlight their value in landscape planning (Bolund & Hunhammar, 1999; Gowdy et al., 2010).

Despite these benefits, it is observed that these local species have been largely overlooked within the context of landscape architecture in the existing literature. In many practical applications, exotic and non-native species are often preferred, leading to incompatibility with local ecosystems and undermining ecological integrity. Such practices not only pose environmental risks but also result in economic and social unsustainability (Sentić, Živojinović & Tomićević-Dubljević, 2022). In contrast, the integration of native species into landscapes not only reduces maintenance and irrigation costs but also contributes to biodiversity conservation and the strengthening of ecological networks (Gómez-Baggethun & Barton, 2013).

The primary aim of this study is to explore the potential use of *Prunus* species that grow naturally in the Van province within the scope of sustainable landscape design. It seeks to evaluate the morphological, phenological, and ecological characteristics of these species and to develop planning-oriented recommendations. Additionally, the study aims to raise awareness among communities, municipalities, and designers, encouraging broader adoption of these local species. In doing so, it aspires to promote the dissemination of nature-based solutions, contribute to climate-friendly urban design, and help preserve the regional landscape identity.

2. Material and Method

The plant material of this study comprises three different *Prunus* (plum) taxa that grow naturally in the Lake Van basin and its surrounding areas. These selected species exhibit distinct morphological and ecological characteristics; they are not only integral components of the local flora but also possess cultivated variants that draw attention in the context of landscape design (Alp, 2019). The taxa examined in the study are defined as follows:

1. ***Prunus divaricata* Ledeb. (Yunus Plum):** This species naturally occurs in the southern parts of Van, particularly around Gevaş. Its fruits appear in various shades of red, yellow, and purple, and it exhibits profuse flowering during the spring. It is observed as a medium-sized shrub or small tree.
2. ***Prunus* × *domestica* L. (Cultivated Plum):** This species has been widely cultivated across Turkey. In the Van region, it commonly exists in semi-natural forms, especially in old gardens and along the edges of wetland areas. It stands out for its high ornamental value, colorful fruits, and broad crown structure.
3. ***Prunus spinosa* L. (Blackthorn):** Characterized by its thorny structure, dense branching, and early-spring white blossoms, this species is a natural component of shrubland vegetation on the northern slopes of Van, particularly in rocky and mountainous areas. It has high potential for use in erosion control and as a boundary plant.

All three species are native to the natural ecosystems of the Van region and possess functional potential in terms of landscape aesthetics, environmental resilience, and cultural representation. The primary criteria for selecting these species include their high adaptation to regional climatic and soil conditions, low maintenance requirements, and multifunctional usability in sustainable landscape design (Karlović, Topić & Mihaljević, 2020; Mihaljević, 2022).

The research methodology is based on qualitative literature review and field-based observations. The data were collected from two primary sources. The first is *Van'ın Doğal Erikleri* (2019) by Şevket Alp, a field-based study providing detailed morphological and ecological data on wild plum species distributed in and around Van. The second is the international publication *Sustainable Landscaping with Prunus* by Karlović et al. (2020), which outlines the role of *Prunus* species in sustainable landscape design and offers functional classifications.

Each species analyzed in the study was evaluated based on the following five key criteria:

1. **Aesthetic and Decorative Value:** The species' contributions to landscape aesthetics were assessed through traits such as crown structure, flower and fruit coloration, leaf texture, and seasonal variations throughout the year.
2. **Ecological Functionality:** The ecosystem services provided by the species were evaluated, including erosion control, soil stabilization, windbreak potential, and drought resistance (Sjöman et al., 2017).
3. **Wildlife Interaction:** The provision of shelter, food, and pollination support for birds, insects, and other wildlife was considered (Hirons & Sjöman, 2019).
4. **Edibility and Local Utilization:** The traditional culinary uses of the species by local communities, as well as their roles in local fruit-gathering and processing culture, were examined. *Prunus* × *domestica* and *Prunus divaricata* were particularly notable in this context.

5. **Sustainable Cultivation Potential:** The species were analyzed in terms of their adaptability to natural conditions, resistance to diseases, low water requirements, and overall suitability for green infrastructure with minimal maintenance needs.

In addition to these criteria, the study also evaluated the potential application forms of each species in landscape design, including:

- Solitary plant (specimen use)
- Group plantings (groves or shrub clusters)
- Roadside tree planting
- Hedge plant
- Pioneer species in ecological restoration

This methodological framework provides a holistic perspective that supports the evaluation of local plant species as multifunctional landscape elements.

3. Findings

Within the scope of this research, three *Prunus* species native to the Lake Van region *P. divaricata*, *P. × domestica*, and *P. spinosa* were evaluated in terms of their potential for sustainable landscape design. Each species was analyzed individually for its aesthetic, ecological, cultural, and functional values. The findings are classified and detailed according to five main criteria as outlined below.

3.1. Aesthetic and Decorative Values

All species included in the study exhibit notable characteristics in terms of landscape aesthetics. *P. divaricata* attracts attention with its dense white-pink blossoms in spring and provides visual diversity with fruit colors ranging from yellow to purple during fruiting season. This trait offers significant advantages in natural landscape areas and recreational green spaces, particularly in terms of color contrast and seasonal flower–fruit cycles.

P. × domestica stands out in fruit orchard designs and in maintaining aesthetic integrity within traditional urban textures due to its abundant fruit yield and foliage that changes from green to red tones. Additionally, the pleasant fragrance released during its flowering period enhances the sensory experience of users.

P. spinosa is predominantly shrub-like and flowers in early spring. The dense white blossoms that cover the branches create strong visual appeal, especially when used as boundary elements. Its compact and natural growth habit makes it ideal as a border species in natural trails, forest pathways, and ecological corridors.

3.2. Ecological Functionality

All three species were found to contribute significantly to ecosystem services. *P. divaricata* supports soil stabilization on dry, sloped areas and enhances soil organic matter through its fruit drop starting in late spring. Its drought and wind resistance make it valuable in sustainable landscape projects in semi-arid climates.

P. × domestica is commonly cultivated near water bodies but can also survive under moderate drought conditions. With its high shading capacity, it helps regulate urban microclimates and contributes to soil moisture retention.

P. spinosa was identified as particularly functional for erosion control. Its thorny, dense growth form serves as a buffer against wind erosion. It is also important for biodiversity, providing microhabitats for local wildlife and limiting the spread of invasive species through its ground-covering capacity.

3.3. Interaction with Wildlife

Field observations revealed that all three species contribute to supporting local wildlife. The fruits of *Prunus divaricata* serve as a vital food source for birds and attract pollinating insects. This supports insectivorous bird species and strengthens pollination networks.

Prunus × *domestica* increases earthworm and microorganism populations in the soil through organic matter accumulation from fallen fruits and leaves, thereby providing indirect benefits to higher trophic levels. Additionally, its rich leaf litter in autumn creates a favorable microclimate for ground-dwelling organisms.

Prunus spinosa offers refuge for birds and small mammals, primarily due to its thorny structure, which provides protection from predators. Its fruits serve as an important food source for birds at the end of the autumn season.

3.4. Edibility and Local Usage Potential

According to field observations and interviews with local residents, all three species have varying degrees of importance in local food culture. The fruits of *P. divaricata* are sold fresh in local markets and are also processed using traditional methods into jams, fruit leather (pestil), and dried products. This highlights not only its economic value but also its contribution to social sustainability.

Prunus × *domestica* is already widely cultivated as a commercial plum and holds significant economic value. However, this study emphasizes the genetic distinctiveness of local varieties found around Van. This uniqueness offers potential for developing region-specific fruit cultivars and for future geographic indication-based branding.

Although the fruits of *Prunus spinosa* are not commonly consumed by humans, they are occasionally eaten fresh in some areas and are also used as animal feed. Moreover, they have potential as a natural flavoring agent in certain traditional fermented beverages.

3.5. Sustainable Cultivation

All evaluated species are suitable for sustainable landscaping strategies due to their low maintenance requirements, adaptive capacity, and compatibility with natural growth forms. *P. divaricata* shows low soil selectivity and can thrive even in poor, calcareous, and rocky soils. Its strong natural competitiveness also makes it effective in resisting invasive species.

Prunus × domestica requires regular pruning and care, yet it demonstrates high adaptability to local climatic conditions. Although it has higher water requirements than the other two species, it still shows moderate drought tolerance. Thus, it is recommended for areas with existing irrigation infrastructure.

Prunus spinosa requires the least intervention in landscape settings. It can grow completely naturally or be densely planted as a hedge species. It exhibits high tolerance to drought, frost, wind, and nutrient-poor soils, making it a suitable option for creating biological buffer zones around rural settlements.

3.6. Usage Types and Design Recommendations

Findings indicate that the three examined species are suitable for the following landscape uses:

- **Specimen Planting:** *Prunus divaricata* and *Prunus × domestica* can be used as focal visual elements due to their striking flowers and fruits.
- **Group Planting:** *Prunus spinosa* and *Prunus divaricata* provide habitat continuity when planted as groves or shrub groups.
- **Roadside Tree:** *Prunus × domestica* is suitable for urban streetscapes due to its regular form and shading capacity.
- **Hedge Planting:** *Prunus spinosa* is ideal for use in rural landscapes as a natural boundary-forming species.
- **Pioneer Restoration Species:** *Prunus spinosa* can be utilized as a pioneer species for greening degraded or marginal lands.

This set of findings offers a comprehensive framework for evaluating native species as multifunctional elements in sustainable landscape design.

4. Conclusion and Discussion

The findings of this study demonstrate that the three *Prunus* species native to the Van region (*Prunus divaricata*, *Prunus × domestica*, and *Prunus spinosa*) possess multifaceted potential for sustainable landscape planning. When compared with similar studies in the literature, the results are noteworthy both in terms of regional specificity and their alignment with the principles of sustainability.

The use of native species in landscape design represents a strategic approach not only for aesthetic purposes but also for enhancing ecosystem services and enabling climate adaptation (Hirons & Sjöman, 2019). The aesthetic value and habitat flexibility of *P. divaricata* are consistent with the criteria for sustainable urban tree selection outlined by Hirons and Sjöman (2019). Similarly, the use of *P. spinosa* as a natural hedge or barrier supports the concept of “functional tree structures” emphasized by Sjöman et al. (2017).

With its semi-cultivated form, *Prunus × domestica* provides a balance between traditional use and urban aesthetics, fitting well into the category of “multifunctional plant species” as defined by Karlović et al. (2020). In this context, the species is especially suitable for traditional urban landscapes and peri-urban transition zones. Furthermore, exploring the productivity of local variants may lay the groundwork for future research in food security and agro-biodiversity.

The findings also highlight the role of native species in preserving cultural landscape identity. The traditional uses of *Prunus* species (e.g., jams, fruit leather, folk medicine) are significant not only from an ecological but also from a cultural continuity perspective. This underlines the necessity of incorporating cultural ecology and ethnobotanical perspectives into landscape architecture. From an ecological standpoint, the wildlife support provided by *Prunus spinosa*—including shelter, food, and pollination resources—is functionally important for strengthening urban ecological corridors and enhancing biodiversity. This aligns directly with the impacts of vegetation on urban fauna as emphasized in *Trees and Urban Ecosystems* (Viljoen & Bohn, 2014).

Nevertheless, certain limitations should be considered when integrating these species into landscape systems. For instance, the thorny structure of *P. spinosa* may reduce user comfort in high-traffic recreational areas. Similarly, *P. × domestica* requires regular pruning, which may increase maintenance costs. However, these limitations can be mitigated through appropriate spatial positioning and design decisions an approach consistent with the principle of "context-sensitive tree selection" proposed by Sjöman et al. (2017).

The study's findings also suggest the suitability of native species for restorative landscape practices. Specifically, *P. divaricata* and *P. spinosa* can serve as pioneer species in the biological rehabilitation of abandoned agricultural lands due to their soil-holding capacity and habitat creation potential. This approach is consistent with the "re-naturalization with native species" model proposed by Mihaljević (2022).

Among the study's limitations are the lack of long-term observational data regarding species growth performance and the absence of empirical assessments of user perception in landscape applications. Future studies should consider supporting these findings with analyses related to climate change scenarios, visual perception, maintenance cost evaluations, and recreational user preferences.

In conclusion, the *Prunus* species native to the Van region offer a rich resource for sustainable landscape design in terms of functional, cultural, socio-economic, and ecological dimensions. Their complementary characteristics make them especially valuable for developing multifunctional and climate-resilient landscape solutions. The conscious integration of these species into landscape planning processes will contribute not only to the preservation of local plant heritage but also to the enhancement of environmental resilience.

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The Music Industry in Liverpool and the Production of Music Venues with Design-Led Approaches

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1. Introduction

Music is a fundamental component of culture and is directly related to pleasure and entertainment (Bowie, 1999; 1). Based on this, we can say that music creates spaces through urban regeneration because entertainment and pleasure have become one of the main products consumed constantly (Passini, 2013; 370). Therefore, in light of this evidence, the formation of musical spaces is inevitable.

In any case, the main aim of European Capital of Culture 2008 was to rehabilitate Liverpool's docklands to encourage an urban renaissance through arts, culture and heritage; as Avery notes, the overall message was that urban waterfronts benefiting from culture and heritage could provide a catalyst for urban renaissance (Avery, 2007; 151-152).

In recent years, music has played a significant role in place-making, implementing policies designed to make our cities more attractive, creative, and competitive. There is abundant evidence that music fosters a sense of belonging, and that this in turn generates ideas of regeneration through cultural clusters and cultural neighborhoods. These practices reveal the transformation of "culture" as a commodity production within contemporary capitalism. Consequently, regeneration plays a crucial role in bridging cultural and economic assets (Hudson, 2006).

On the other hand, "the major northern British cities of Liverpool, Manchester, and Sheffield have sought to develop specific cultural neighborhoods with music and culture as part of new economic development and regeneration strategies" (Hudson, 2006; 631). In this context, the primary aim of this chapter is to evaluate the role of music in placemaking and regeneration in Liverpool and to demonstrate the link between music, identity, and place.

Fundamentally, there is strong evidence that music is deeply connected to identity and place, but the key point to consider is the global dynamics of music.

While Cohen demonstrates the importance of music in creating a way of life, identity, and sense of belonging in Liverpool, he nevertheless acknowledges that the process of globalization has undermined these implications. Another interpretation is that music can create spaces, both literally and metaphorically. This is achieved through social relations and interactions in everyday life, aided by the existing built environment, but this remains a contested process (Hudson, 2006; 627).

Firstly, the Scouse accent is one of the most important factors influencing the sense of belonging in Liverpool. A number of lyrics are written in the Scouse accent, most notably the street song "Maggie Mae", Dominic Behan's "Liverpool Lou" and "In My Liverpool Home". Furthermore, "the sonorous landscape of spoken word is central to patterns of inclusion and exclusion and is a significant cultural symbol of people and place". Merseybeat, for example, symbolised Liverpool with its unique music industry (Strachan, 2010; 49-50).

Most notably, the importance of the Beatles, the famous English rock band originating from Liverpool, in creating music venues and defining Liverpool's cultural identity should be noted. The Beatles always presented themselves as a local band; in fact, they were quite famous worldwide. The band's reflections on their cultural identity were exploited during the ECoC 2008 event in Liverpool, attracting large numbers of tourists to locations such as the Beatles Story, John and Paul's National childhood home, and the Beat Goes On exhibition at the World Museum Liverpool (Leigh, 2010; 30, 40). Furthermore, Penny Lane and Strawberry Field orphanages, where John Lennon spent his childhood, have long been featured on travel itineraries, and the Matthew Street area is considered the birthplace of Liverpool's bohemianism (Daniels, 2006; 29; Strachan, 2010; 125). Furthermore, the Beatles' music of the 1960s fostered the emergence of two imaginary geographies in Liverpool: Bohemia and Suburbia (Daniels, 2006; 31).

Meanwhile, the Beatles-themed Hard Days Night Hotel, which opened in 2004, is an important model of "theming", which gives meaning and symbolism to a space and defines what it really is (Bryman, 2004; 15, 32).

1.1. Landscapes of Music in Liverpool

There are broader assumptions that not only do places create musical landscapes, but that music-making also helps to produce and shape places. The connection between the two characterises Liverpool as a profoundly musical city (Lashua, Cohen & Schofield, 2010, 127).

Lashua, Cohen, and Schofield highlight three iconic spaces within Liverpool's popular music landscape and heritage: the Cavern Club, Eric's Club, and Cream. These venues highlight Liverpool's distinctly musical characteristics and reflect key moments in Liverpool's musical heritage, which were intertwined with the city's social, cultural, and economic landscape during the 1960s, 1970s, and 1990s. They can also be categorized as cultural quarters. "These venues continue to have a profound impact on the characterization of Liverpool's musicians and music-making culture" (Lashua et al., 2010, p. 128).

Since the emergence of a vibrant club culture, these clubs have influenced cultural life, contemporary imagery, the nightlife economy, and even urban regeneration policies and strategies. Indeed, many nightclubs, such as Voodoo, Garlands, and Chibuku, have been built to help change the relationship between a city's culture and geography (Young, 2010, 143).

Liverpool ECoC 2008 also saw over 7,000 arts, culture and music performances launched at venues across the city, including "Liverpool One", a Beatles-themed hotel, and other venues around the Docklands. Lashua et al. (2010) suggested three public pairings to showcase Liverpool's musical identity.

Additionally, certain brochures and technological products play a significant role in promoting and guiding Liverpool's music landscape. For example, the book "Sound City: A Guide to Liverpool's Music Heritage," a tourist map produced for the cultural capital, is a prime example of this. This map identifies dilapidated and abandoned buildings and lists music and entertainment venues in the neighborhoods (Lashua et al., 2010; 131-133).

In addition, the Up the Hill Map, roughly centered on Hardman Street, includes a mix of student-centered nightlife and outlines the boundaries of the city's cosmopolitan ghetto (Lashua et al., 2010; 134-136).

1.2. Music Places Regenerated

During the 1970s, Liverpool Underground was dominated by three venues: The Moonstone, which will be remembered as one of the most prominent heavy metal venues and where fans were known to form close relationships with the bands that played there; The Sportsman, which had good access to the city’s transport services; and the Star and Garter, which could be described as a large, bright house with a packed house (Cohen & Lashua; 2010; 66-73).

There is evidence that music making has been influenced by urban regeneration initiatives, initially concerned with economic development, but there are also links between music making venues and retail developments (Cohen & Lashua, 2010; 76).

Originally a synergy of entertainment and retail, St. John's Market and District was built in 1422 in response to Liverpool's rapidly expanding urbanization. The venue became a preferred venue for working-class entertainment, with its lively musical atmosphere, in the final decades of the 19th century. After World War II, the area was deteriorated and revitalized in 1962 as part of a redevelopment project. The revitalization plan included relocating residents to the city's suburbs and encouraging economic development and investment; the plan's primary goal was to transform St. John's Market and District into an entertainment and shopping center. After implementing numerous urban initiatives, the district opened in 1971, but economic conditions in Liverpool deteriorated, and the plan was met with considerable criticism. However, several musicians interviewed by Cohen and Lashua noted that "the basement of the district was very vibrant for a time, providing a unique musical and creative space that provided opportunities for public performance at a time when such opportunities were disappearing from the city center."

Second, Clayton Square and Liverpool One, as distinct music and retail landscapes, gained momentum after urban regeneration initiatives were implemented for the area. Clayton Square shopping centre was built in the 1970s and 1980s to address the demand for leisure and entertainment, which was seen as a means of attracting shoppers (Figure 1 and Figure 2). In the 1990s, the shopping centre, along with other suburban shopping centres, became industrial shopping centres. Subsequently, "the forty-two-acre site was redeveloped to create a new regeneration scheme called Liverpool One, described by policymakers as Europe's largest shopping development and key to Liverpool's remarkable renaissance" (Cohen & Lashua, 2010, p. 78-79).

Figure 1. Clayton Square: Old Version (URL 1).

Figure 2. Clayton Square: New Version (URL 1).

It is worth noting, however, that St. John's and Clayton Square were marginalized after the construction of the Liverpool One project, but these were generally integrated into the city with a mix of entertainment and retail activities to attract tourists (Figure 3). This was intended to rebrand the area as a consumer center. However, musicians have suffered from such policies; for example, music venues are not protected against neoliberal trends, thus neglecting local music making (Cohen & Lashua, 2010; 79-80).

Figure 3. A Musical Experience in Liverpool One.

There are also many nightclubs such as Baa Bar, Lloyd's Bar and Walkabout that were built or transformed with modern design approaches by the urban development company Urban Splash (Young, 2010; 154).

The findings of St. John's and its rock pubs have shown increasing evidence of a close link between music, heritage, and urban regeneration. Furthermore, some evidence in recent years has shown that "Europe and North America are not only involved in urban regeneration through retail but also through culture." Furthermore, cultural influences benefit from the uniqueness of cities in terms of attracting tourist visits and fostering competitiveness (Cohen & Lashua, 2010; 80).

Finally, in many cities in the United Kingdom, including Liverpool, there have been discussions about the tensions between cultural heritage, local distinctiveness, and cultural regeneration. These discussions have been fueled, for example, by the conversion of shipping areas in the port area into commodified tourism and museum spaces with commemorative value. Furthermore, different parts of the city have been transformed into distinctive cultural districts for musical heritage and retail, such as the "Cavern Quarter," centered around the Cavern Club on Mathew Street, the venue immortalized by the Beatles (Figure 4, Figure 5 and Figure 6). This area includes the Rope Walks cultural district, a rock music venue now home to popular bars and nightclubs, and is symbolized by forgotten venues such as the Munro Pub (Lashua, 2011).

Figure 4. Mathew Street.

Figure 5. The Cavern Club.

Figure 6. Cavern Quarter (URL 1).

This is clearly exemplified by Liverpool's regeneration into a music city, drawing on the legacy of the Beatles, Merseyside, and post-punk traditions during its time as a European capital of culture. Consequently, we can argue that "culturally driven urban regeneration has influenced the characterization of music and music venues as local heritage and provoked the construction of alternative and contested musical heritage" (Cohen & Lashua, 2010; 80-81).

2. Material and Method

The study is derived from theoretical and research-oriented articles on the creation of space through music in Liverpool and from a master's thesis written in 2014. In addition, field notes and photographs obtained in 2013 were also used in certain areas of the study.

The primary objective of this study is to evaluate the role of music in Liverpool in the context of place-making and regeneration, and to demonstrate the connection between music, identity, and place. The cultural industries and cultural quarters that emerged in the context of music place-making, particularly in the context of regeneration, represent the specific dynamics of music in urban space. This reveals the dominant aspects of integrated urban design in the city. In this context, we examine the evidence that music, particularly through the work of Liverpool legends the Beatles, creates specific active frontages and activates genius loci.

Finally, within the scope of Liverpool 2008: European Capital of Culture, the cultural and economic values brought to the city by the Beatles tourism are also evaluated within the scope of the study.

3. Findings and Discussion

In recent years, one of the methods used as a tool for urban development has been cultural regeneration. This is made possible by improving the quality of urban life through cultural quarters. In Liverpool's case, this can be expressed as creating cultural quarters where music is practically breathed into the space and supporting quality of life through the creation of music spaces through various urban design principles.

In Liverpool in particular, mixed-use projects, environmental improvement plans and especially public art are highlighted, arguing that urban design is an essential part of the process of cultural regeneration.

Culture should be seen as a complex entity, as a process as well as a product, as a way of life as well as an artefact, as a mode of production as well as a mode of consumption (Wansborough & Mageean, 2000).

Experience with culture in Britain has so far been quite limited. There are a few exceptions, notably Liverpool and Glasgow. Cultural regeneration, on the other hand, is more often seen as a derivative of general arts, community, and economic policies. However, the use of culture in urban regeneration in Britain is increasing because it is linked to a better understanding of the links between culture and more traditional techniques such as land-use planning and economic development (Wansborough & Mageean, 2000).

In this regard, particularly during Liverpool's 2008 European Capital of Culture campaign, music was a crucial element in the implementation of cultural policies in the European Capital of Culture 2008, which ranked second only to "international status" (Avery, 2007; 156). The European Capital of Culture, in particular, provided numerous opportunities for young people to showcase their amateur performances abroad. The primary objective in achieving this was to contribute to the development of economic and cultural vitality and tourism.

Integrating the role of music within the context of cultural access and participation is a key objective to foster social change and social cohesion. Nightlife, the Beatles museum, and gallery have played a significant role in fostering cultural interest and participation.

Needless to say, Liverpool has a significant number of cultural assets and the main aim was to maintain the popular music scene, existing ones such as museums and galleries and a strong independent visual arts tradition within the context of cultural vitality.

Meanwhile, the European Capital of Culture has also allowed many to openly witness "The Beatles Tourism." It is estimated that the Mathew Street festival attracts approximately 350,000 tourists and brings approximately £32 million to Liverpool each year (Richards & Palmer; 2010; 174).

Therefore, the music industries and music venues created with a deep-rooted musical history have become the centre of cultural identity and accumulation in Liverpool over time, making the city an important global centre that promotes it internationally.

4. Conclusion and Suggestions

Music plays a crucial role in bridging the gap between Liverpool's cultural and economic assets. It provides Liverpool with a way of life, a sense of identity, and a sense of belonging. In other words, it can help create and shape music venues. Furthermore, it's worth noting that the Beatles and their contributions to the city, the theme phenomenon, propelled the city onto the international stage, particularly during the 2008 European Capital of Culture designation, which increased the city's competitiveness and dynamism. In other words, music is a treasure trove for Liverpool, both for future urban regeneration policies and for promoting the city's reputation globally.

Contemporary popular music can be said to exist somewhere between increasing globalization on the one hand and increasing localization on the other. Certain developments in the city have given local communities greater access to music production and consumption. Therefore, it can be argued that to the extent that local dynamics utilize and develop music as a commodity, the music industry will strengthen and, along with the Beatles factor, integrate it into global dynamics. Furthermore, opening music studios for young people in established cultural quarters could be a radical solution for both the continuity of the city's music culture and the development of its local dynamics (Cohen, 2006; 332-346).

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Fragrance in Landscape Architecture: Exploring the Sensory and Cognitive Dimensions of Scented Plants

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1. Introduction

In today's increasingly dense urban life, the bond between humans and their environment has been weakening. This phenomenon has led to the dominance of a visually oriented culture of perception in modern societies (Çakır & Tuğluer, 2022). However, spatial experience is not limited to forms perceived only by the eye; rather, it gains meaning through the participation of all the senses. The concept of sensory landscape emerges as an approach that interprets this holistic perception through all five senses. This perspective requires evaluating the environment not only visually, but also through olfactory, auditory, tactile, and even gustatory dimensions.

The sense of smell is regarded as one of the most powerful senses in terms of evoking emotional responses and leaving lasting traces in memory within the framework of sensory integrity. Odors reach the emotional centers of the brain directly through the limbic system, establishing strong connections with memories, a sense of belonging, and patterns of behavior. Therefore, smell is not merely considered an aesthetic stimulus but also a psychological and cultural means of interaction. In landscape design, the use of scent forms a sensory layer that deepens the relationship between humans and space.

The role of scent in landscape design is evaluated on three main levels. The first is the biochemical level, which examines the mechanisms of scent production in plants and the chemical structure of volatile components. These compounds are regarded as key factors that determine both the environmental adaptation and aesthetic value of plants. The second is the cognitive and emotional level, which focuses on the relationship between smell and spatial memory. Scents evoke emotional traces of the past in individuals and enhance their awareness of space. At the design level, the aesthetic, guiding, and psychological functions of fragrant plants in landscape planning are discussed. This level concerns the deliberate and systematic use of scent within spatial composition (Çakır et al., 2022)

Smell adds a depth that goes beyond visual perception in environmental design, strengthening the memorability of the place, user satisfaction, and emotional integrity. Studies have shown that individuals tend to spend longer periods of time, experience lower stress levels, and develop more positive attitudes in spaces where pleasant scents are present. Therefore, smell has become an indispensable component of landscape architecture as an aesthetic, psychological, and social value. The presence of scent in landscape design transforms space from being a merely visible environment into one that is felt, remembered, and lived. This perspective constitutes the essence of the sensory landscape approach.

2. Senses and Perceptıon

At the core of the human relationship with the environment lie the senses. They transform physical stimuli from the external world into neural signals that give rise to perception. The five primary senses sight, hearing, touch, taste, and smell constitute the essential components of environmental awareness and emotional response. These senses do not function independently but operate in continuous interaction, a phenomenon known as sensory integration (Solso et al., 2005).

Throughout history, particularly within Western thought, vision has been associated with knowledge, reason, and civilization, while the senses of touch, taste, and smell have often been regarded as more bodily and primitive. This sensory hierarchy has influenced architecture and landscape design for centuries, establishing a visually centered paradigm. However, spatial experience is not limited to what is seen; it also encompasses what is heard, felt, and smelled. For a space to be perceived holistically, all senses must be considered together (Classen, 1997; Howes, 2002; Pallasmaa, 2024).

The sense of smell differs from other sensory modalities in that olfactory information is processed directly within the limbic system. Consequently, scents can evoke emotional responses even before conscious awareness arises. Pleasant or unpleasant odors influence behavioral interaction with the environment, functioning not only as aesthetic stimuli but also as behavioral cues (Wilson & Stevenson, 2006; Marks, 2013; Herz, 2016; Spence, 2020).

From a landscape design perspective, a multisensory approach enriches user experience and strengthens spatial memorability. For instance, a garden infused with the scent of lavender is remembered not only for its form but also for the sense of tranquility it evokes. Considering the senses holistically transforms space from a visual object into a lived and felt experience. This understanding reaffirms the importance of sensory diversity as a fundamental dimension in contemporary landscape design (Pallasmaa, 2024).

3. Biochemical Characteristics of Fragrant Plants

Pleasant plant fragrances primarily originate from volatile organic compounds (VOCs), classified as secondary metabolites. These substances play crucial roles in growth, defense, pollination, and adaptation. Volatile components in the plants consist of monoterpenes, sesquiterpenes, phenylpropanoids, esters, and aldehydes function as the plant's chemical communication tools with its environment (Croteau et al., 2000; Dönmez & Salman, 2017).

3.1. Biosynthesis and Storage of Volatile Components

Volatile Components are synthesized mainly through two pathways: the mevalonate (MVA) pathway in the cytoplasm, responsible for sesquiterpene production, and the methylerythritol phosphate (MEP) pathway in plastids, which forms monoterpenes and diterpenes (Dudareva & Pichersky, 2004). Sesquiterpenes are linked to plant defense, whereas monoterpenes dominate floral scents. Environmental variables such as light, temperature, and humidity significantly influence their biosynthetic efficiency (Knudsen et al., 2006).

Volatile components are stored in glandular trichomes, secretory canals, or oil glands depending on the species. For example, *Lavandula angustifolia* and *Mentha piperita* accumulate volatiles in leaf and flower trichomes, whereas *Laurus nobilis* and *Rosmarinus officinalis* store them in internal canals (Werker, 2000; Figueiredo et al., 2008). These mechanisms illustrate how biochemical regulation enables plants to maintain ecological interactions and resilience under environmental stress (Özderin et al., 2014).

3.2. Ecological and Sensory Functions of Volatile Components

Volatile components in the plants mediate the plant's interaction network by performing defensive, pollination, and allelopathic functions. Terpenoids and phenylpropanoids deter herbivores and pathogens; floral volatile components attract pollinators, while some species release chemicals that suppress competitors (*Salvia officinalis*, *Eucalyptus* *globulus*) (Pichersky & Gershenzon, 2002; Knudsen et al., 2006). The olfactory profile of a plant is determined by the composition and dominance of specific volatiles. *Rosa damascena* and *Jasminum officinale* are rich in linalool and geraniol, producing soft floral scents; *Lavandula angustifolia* and *Mentha piperita* yield fresher notes from linalool and menthol; *Rosmarinus officinalis* and *Salvia officinalis* emit cineole and pinene, resulting in sharper, resinous aromas (Prusinowska & Śmigielski, 2014; Andrade et al., 2018; Başer & Buchbauer, 2015; Özcan & Dönmez, 2018) (Table 1). Because multiple species share similar volatile components such as linalool and cineole, they can produce comparable scent impressions even when taxonomically distant. This biochemical and perceptual overlap allows designers to employ plants with complementary olfactory signatures to enrich the sensory quality of landscape compositions (Sell & Sell, 2006; Dönmez, 2016).

Table 1. Plant Species Used for Their Scent in Landscape Design, Their Fragrance Characteristics, and Major Compounds.

Plant Species	Family	Main Components	Fragrance Character
Acacia dealbata	Fabaceae	Farnesol, benzaldehyde	Sweet, honey-like
Crocus sativus	Iridaceae	Safranal	Warm, aromatic
Jasminum officinale	Oleaceae	Benzyl acetate, indole	Intense, exotic
Laurus nobilis	Lauraceae	1,8-Cineole, eucalyptol	Spicy, fresh
Lavandula angustifolia	Lamiaceae	Linalool, linalyl acetate	Floral, relaxing
Magnolia grandiflora	Magnoliaceae	Linalool, geraniol	Elegant, floral
Mentha piperita	Lamiaceae	Menthol, menthone	Cool, refreshing
Ocimum basilicum	Lamiaceae	Linalool, eugenol	Fresh, aromatic
Pelargonium graveolens	Geraniaceae	Citronellol, geraniol	Fresh, lemon-like
Pinus pinea	Pinaceae	α-, β-Pinene	Resinous, fresh
Rosa damascena	Rosaceae	Geraniol, citronellol	Sweet, floral
Rosmarinus officinalis	Lamiaceae	Cineole, borneol	Woody, sharp
Salvia officinalis	Lamiaceae	Thujone, cineole	Spicy, strong
Thymus vulgaris	Lamiaceae	Thymol, carvacrol	Herbal, intense

4. Smell And Spatial Memory

The sense of smell is one of the most powerful links between perception and memory. Unlike other senses, olfactory signals bypass the thalamus and are processed directly by the limbic system specifically the amygdala and hippocampus, regions responsible for emotion and long-term memory (Wilson & Stevenson, 2006). Consequently, odors can unconsciously trigger vivid recollections and emotional responses, reactivating memories long thought forgotten. This connection is often described as the Proust effect, named after Marcel Proust's literary depiction of involuntary memory triggered by smell (Chu & Downes, 2000). While visual and auditory impressions tend to fade, familiar scents can recall past experiences with striking emotional accuracy. Smell thus operates not merely as a perceptual stimulus but as a bridge between sensory experience and emotional memory.

4.1. The Psychological Impact of Smell on Memory

Olfactory stimuli exert measurable psychological effects. Pleasant fragrances activate the parasympathetic nervous system, lowering stress and fostering relaxation (Herz, 2016). Essential oils such as *Lavandula angustifolia* (lavender) and *Citrus bergamia* (bergamot) increase alpha brain waves, inducing calm and mental clarity (Lis-Balchin, 2006). For this reason, fragrant species are frequently incorporated into therapeutic gardens and healthcare landscapes. Scents also reinforce emotional attachment to place. Smells encountered during childhood often evoke nostalgia in adulthood, helping individuals reconnect with personal or cultural memories. The earthy aroma of petrichor produced by rainfall on dry soil exemplifies how olfactory cues evoke harmony with nature and enhance environmental awareness (Henshaw, 2013). In this sense, smell acts as an invisible yet potent medium shaping both emotional and spatial memory.

4.2. The Role of Smell in Spatial Identity and Wayfinding

Spatial identity arises from the sensory and cultural coherence a place establishes within memory. Each environment possesses a distinctive scent profile that becomes part of its identity and collective memory. Within urban contexts, the concept of urban smellscape highlights that cities can be experienced not only visually but also olfactorily, where scent becomes integral to belonging and recognition (Henshaw, 2013). Olfactory perception also aids spatial orientation. Although diminished through evolution, humans subconsciously use odor cues for wayfinding (Stevenson, 2010). For instance, the presence of linder in a park may act as a natural landmark in cognitive mapping. Approaches such as smellwalks and sensory mapping enhance the legibility of landscapes, supporting intuitive navigation (Thibaud, 2011). When consciously integrated into design, olfactory layers transform spaces into multisensory experiences places that are not only seen but also felt and remembered (Pallasmaa, 2024).

5. The Use of Fragrant Plants in Landscape Desıgn

Scent, as a design element, transcends visual aesthetics and transforms spatial experience into a multisensory encounter. Fragrant plants engage users on both emotional and cognitive levels, enriching the atmosphere and shaping the perception of place. Therefore, olfaction is regarded not only as an aesthetic attribute but also as an environmental component that influences psychological, behavioral, and functional responses (Henshaw, 2013; Spence, 2020). A well-composed olfactory design can transform the ambiance of a space and create a lasting sensory connection between users and their environment.

5.1. The Contribution of Scent to Design and Plant Selection

Fragrant plants serve three essential roles in landscape design: sensory, orientational, and aesthetic. Sensory functions involve emotional balance, stress reduction, and enhanced user satisfaction through pleasant odors (Herz, 2016; Spence, 2020). The orientational role derives from the use of scent intensity and distribution to aid spatial legibility and wayfinding (Henshaw, 2013). Aesthetically, the combination of color, texture, form, and scent creates a cohesive perceptual unity that deepens spatial experience (Lis-Balchin, 2006).

When selecting species, ecological compatibility, soil conditions, seasonal continuity, and scent diffusion must be considered (Tuğluer & Çakır, 2021). Highly aromatic species such as *Gardenia jasminoides* or *Lilium candidum* should be used sparingly in small spaces to avoid sensory saturation, while mild-scented plants such as *Lavandula angustifolia*, *Rosmarinus officinalis*, and *Salvia officinali*s are ideal for high-traffic areas, promoting a sense of freshness. Arranging plants with overlapping blooming periods allows for a "scent cycle" that maintains olfactory continuity throughout the year. In addition, volatile components emitted by these plants not only shape human sensory experiences but also enhance pollinator activity and biodiversity (Dudareva & Pichersky, 2004; Maffei, 2010).

5.2. Sensory Gardens and User Experience

The concept of sensory gardens has emerged as a contemporary design approach that allows all users, including those with visual impairments, to experience landscapes through smell, touch, and hearing. For instance, the Kew Gardens in the United Kingdom incorporates design elements that engage the senses of sight, smell, sound, touch, and taste, aiming to enhance accessibility and sensory awareness (Royal Botanic Gardens, Kew, 2024). Similarly, in Japan, “Aromatic Gardens” featuring plant species such as lavender, basil, and mint offer visitors dynamic olfactory experiences that change with the seasons.

Research indicates that natural plant odors are generally perceived as more pleasant and restorative than artificial or urban odors (Pálsdóttir et al., 2021). Scents contribute to emotional attachment and spatial memory, reinforcing the user’s connection with the environment (Herz, 2016). Thus, fragrant plants function not merely as decorative components but as design tools that promote psychological well-being, relaxation, and social interaction within outdoor spaces.

5.3. Design Principles, Practical Challenges, and Future Directions

The integration of olfactory elements into landscape design requires adherence to certain principles. Layered scent composition ensures year-round continuity through plants with staggered flowering periods. Spatial legibility uses scent as a natural navigational cue. Balance and compatibility combine strong and subtle fragrances to maintain harmony. Ecological sustainability favors native flora to strengthen environmental resilience (Xiao, 2018; Lygum & Xiao 2025).

Despite these principles, challenges persist in measuring and controlling olfactory experiences in outdoor environments. Factors such as wind direction, humidity, and temperature significantly influence scent perception, while user response remains subjective and culturally variable (Dönmez & Tuğluer, 2022). Recent studies propose participatory methods such as smell-walks, scent mapping, and multisensory participatory design, which connect human perception directly to spatial planning (Barau et al., 2023; Liang et al., 2023). Ultimately, fragrant plants transform landscapes from purely visual compositions into emotionally and cognitively engaging environments. By incorporating scent as a design layer, landscape architects can promote place identity, ecological sustainability, and human well-being, making olfaction one of the most effective tools in contemporary sensory landscape design.

6. Conclusion and Suggestions

In contemporary landscape architecture, spatial experience is no longer defined solely by visual aesthetics but by the interaction of all senses. Within this multisensory framework, scent has gained renewed importance as a design element that transforms a space from something merely seen into something felt and remembered. Fragrant plants play a crucial role in shaping emotional balance, spatial identity, and environmental perception. However, not every aromatic species achieves these effects equally. The intensity, composition, and ecological adaptability of each plant determine its impact on the user experience. Therefore, the use of species with natural distribution and high adaptation to local climatic conditions is recommended to ensure both sensory harmony and ecological compatibility.

In arid and semi-arid regions, drought-tolerant aromatic plants such as lavender, rosemary, and sage are particularly effective. These species enhance biodiversity, support pollinators, and maintain visual and sensory richness while minimizing water consumption. Their integration into xeriscape-oriented designs is recommended as a means of combining sensory quality with sustainable landscape practices. Although challenges remain in quantifying and controlling scent in outdoor environments, recent developments in scent mapping and sensory analysis methods have provided new opportunities for incorporating olfactory data into landscape planning. Further research is recommended to refine these methods and to explore the physiological and psychological responses associated with natural plant fragrances.

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The Shading Problems of Responsive Facades in Manhattan

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1. The Architectural Types of Facades in Manhattan

The architectural landscape of Manhattan is characterized by a diverse array of façade types that reflect the city's historical evolution, cultural influences, and technological advancements. The façades of Manhattan's buildings serve not only as protective barriers against environmental elements but also as significant aesthetic and cultural markers that communicate the identity of the structures and the city itself. This response aims to explore the various architectural façade types found in Manhattan, drawing on a range of scholarly sources to provide a comprehensive overview.

One of the most prominent façade types in Manhattan is the curtain wall, which has gained popularity due to its ability to provide extensive design freedom while protecting the building's interior from external climate conditions. Curtain walls are typically non-load-bearing and are attached to the building's structural frame, allowing for large expanses of glass that enhance natural light and views (Klein, 2013). This façade type is particularly prevalent in modern skyscrapers, where the use of glass and steel creates a sleek, contemporary appearance that is emblematic of Manhattan's skyline. The integration of energy-efficient materials and technologies into curtain wall systems has also become a critical focus, as architects strive to meet rising energy-saving requirements (Sandak Sandak, Brzezicki & Kutnar, 2019).

In addition to curtain walls, responsive façades are emerging as a significant trend in Manhattan's architectural design. These façades are designed to adapt to environmental conditions, such as sunlight and temperature, thereby optimizing energy consumption and enhancing occupant comfort (Ningsih et al., 2023). The concept of responsive architecture is rooted in the need for buildings to interact dynamically with their surroundings, which is particularly relevant in a densely populated urban environment like Manhattan. The incorporation of kinetic elements and smart technologies into façades allows for a more sustainable approach to building design, addressing both aesthetic and functional needs (Pesenti, Masera, Fiorito & Sauchelli, 2015).

Another notable façade type is the traditional masonry façade, which reflects Manhattan's historical architectural styles. These façades often feature intricate detailing, such as cornices, pilasters, and decorative elements that convey a sense of craftsmanship and permanence. The use of brick, stone, and terra cotta in these façades not only contributes to the aesthetic appeal but also provides durability and insulation (Sandak et al., 2019). The preservation of these traditional façades is crucial for maintaining the historical character of neighborhoods within Manhattan, as they serve as tangible links to the city's architectural heritage.

The concept of the "Manhattan World" is also relevant when discussing the architectural façades of the city. This term refers to the predominance of orthogonal building geometries and planar surfaces that characterize urban environments like Manhattan (Vanegas, Aliaga & Benes, 2012). The Manhattan World assumption facilitates various computational approaches to urban reconstruction and façade analysis, enabling architects and urban planners to better understand and manipulate the spatial relationships between buildings (Li, Wonka & Nan, 2016). This framework has implications for both the design and analysis of façades, as it emphasizes the importance of alignment and orientation in urban settings.

Moreover, the integration of advanced technologies, such as 3D scanning and point cloud analysis, has revolutionized the way façades are documented and reconstructed. These technologies allow for precise modeling of existing structures, enabling architects to create accurate representations of façades for restoration or renovation projects (Li, Zhang, Ai & Lin, 2016). The ability to analyze façades through digital means has also opened new avenues for exploring innovative design solutions that respect historical contexts while embracing modern aesthetics (Nishida, Bousseau & Aliaga, 2018).

The role of façades in conveying cultural and political meanings cannot be overlooked. As noted by Koolhaas, façades serve as a metonym for architecture, embodying the cultural narratives and values of their time (Timmer, 2020). In Manhattan, this is particularly evident in the use of media façades, which transform buildings into dynamic canvases for artistic expression and public discourse. These façades often incorporate digital technologies that allow for the projection of images and information, thereby engaging the public in new and interactive ways (Colangelo, 2019). The emergence of media architecture reflects a broader trend towards integrating technology into the built environment, challenging traditional notions of façade design.

Sustainability is another critical consideration in the design of façades in Manhattan. The increasing focus on green architecture has led to the development of innovative façade systems that incorporate sustainable materials and technologies. For instance, the use of green walls and living façades not only enhances the aesthetic quality of buildings but also contributes to urban biodiversity and air quality improvement (Aldeek, 2020). These sustainable façades are designed to mitigate the urban heat island effect and promote energy efficiency, aligning with the city's broader environmental goals.

The diversity of façade types in Manhattan also reflects the city's socio-economic dynamics. Architectural styles often vary based on the historical context, economic conditions, and cultural influences of different neighborhoods. For example, the façades of luxury residential buildings may feature high-end materials and elaborate designs, while those in lower-income areas may prioritize functionality over aesthetics (Shan & Zhang, 2022). This disparity highlights the role of façades as indicators of socio-economic status and urban identity.

Furthermore, the impact of climate on façade design is increasingly recognized as a vital factor in architectural practice. Climate-responsive façades are being developed to address the unique environmental challenges faced by buildings in Manhattan, such as extreme temperatures and varying sunlight exposure (Napier, 2015). By incorporating passive design strategies and advanced materials, architects can create façades that enhance energy efficiency and occupant comfort while minimizing the building's carbon footprint.

In summary, the architectural façades of Manhattan represent a rich tapestry of styles, materials, and technologies that reflect the city's historical evolution and contemporary challenges. From curtain walls and responsive façades to traditional masonry and media architecture, each façade type contributes to the overall character of the urban landscape. The integration of sustainability, advanced technologies, and cultural narratives into façade design underscores the importance of façades as both functional and expressive elements of architecture. As Manhattan continues to evolve, the exploration of innovative façade solutions will remain a critical aspect of architectural practice in the city (Figure 1).

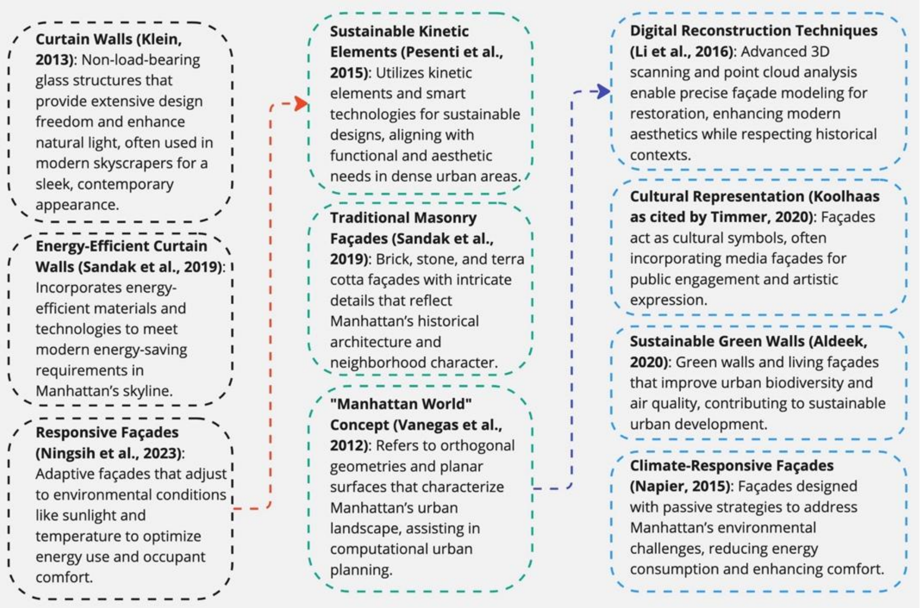

Figure 1. The Architectural Facade Types of Manhattan.

2. Responsive Facades in Metropolitan Areas

Responsive facades, particularly in metropolitan areas, represent a significant advancement in architectural design, focusing on the dynamic interaction between buildings and their environmental conditions. These adaptive facades (AFs) are engineered to respond to fluctuating weather patterns, occupant preferences, and energy efficiency requirements, thereby enhancing indoor comfort and reducing energy consumption. The integration of various technologies, such as shape memory polymers (SMP) and electrochromic glazing, allows these facades to adjust their configurations in real-time, optimizing thermal performance and daylighting while minimizing glare and discomfort for occupants (Attia et al., 2018; Zameem, 2023; Valitabar et al, 2022).

The concept of climate-adaptive building shells (CABS) encompasses a range of facade technologies that can modify their properties based on external stimuli. This adaptability is crucial in urban environments where buildings face diverse climatic challenges. For instance, studies have shown that dynamic facades can significantly improve energy performance by balancing solar control and daylight admission, which is essential in densely populated areas where energy demand is high (Bakker Oeffelen, Loonen & Hensen, 2014; Kasinalis, Loonen, Cóstola & Hensen, 2014). Moreover, the implementation of automated systems in facades allows for a more nuanced response to environmental changes, enhancing user satisfaction and overall building performance (Valitabar et al., 2022; Bakker et al., 2014).

In addition to energy efficiency, responsive facades contribute to urban sustainability by incorporating green elements, such as vertical gardens. These green facades not only improve air quality and reduce the urban heat island effect but also enhance the aesthetic appeal of buildings (Aung, 2023; Moghaddam, Mir, Navarro & Redondo, 2021). The multifunctionality of green facades aligns with the goals of sustainable smart building design, as they provide ecological benefits while also serving as effective thermal insulators (Moghaddam et al., 2021). Furthermore, the integration of renewable energy technologies, such as photovoltaic panels within dynamic facades, presents an innovative approach to energy harvesting, allowing buildings to generate their own energy while maintaining comfort levels for occupants (Ożadowicz & Walczyk, 2023).

The design and implementation of responsive facades are not without challenges. The initial costs and complexity of installation can be significant, and there is a need for ongoing research to optimize these systems for various climatic conditions and building types (Özdemir & Çakmak, 2022). Nevertheless, the potential benefits of adaptive facades in enhancing indoor environmental quality (IEQ) and reducing energy consumption make them a promising solution for modern urban architecture (Choi, Loftness, Nou, Tinianov & Yeom, 2019; Nady, 2017). As cities continue to grow and face the impacts of climate change, the adoption of responsive facades will likely play a crucial role in creating resilient and sustainable urban environments.

3. The Relationship Between Shading and Responsive Facades in Architecture

The relationship between shading and responsive facades in architecture is a multifaceted topic that encompasses various technological, ecological, and aesthetic considerations. Responsive facades, which adapt to changing environmental conditions, are increasingly recognized for their potential to enhance energy efficiency, improve occupant comfort, and contribute to sustainable architectural practices. Shading devices, as integral components of these facades, play a crucial role in regulating light and heat, thereby influencing the overall performance of buildings. Responsive facades are designed to dynamically adjust their properties in response to external stimuli, such as sunlight, temperature, and humidity. This adaptability is essential for optimizing indoor environmental quality while minimizing energy consumption. For instance, the implementation of shading systems within responsive facades can significantly reduce solar heat gain, which is particularly beneficial in hot climates. Research indicates that arrays of hygromorphs, inspired by bacterial spores, can be utilized as shading devices that respond to humidity changes, thereby providing a highly responsive shading solution that can be integrated into double-skin facades (Birch, Bridgens, Zhang & Dade-Robertson, 2021). Such innovations highlight the potential of biomimetic approaches in architectural design, where natural mechanisms inform the development of adaptive systems.

Moreover, the geometric and material properties of shading devices are critical in determining their effectiveness. The Flectofold system, which mimics the folding mechanisms of the aquatic plant Aldrovanda vesiculosa, exemplifies how compliant structures can be employed to create dynamic shading solutions. This system allows for extensive geometric motion amplification, enabling a one-dimensional actuation force to produce a three-dimensional closing motion, thus enhancing shading performance without the need for complex mechanical systems (Körner et al., 2017). Such designs not only improve functionality but also contribute to the aesthetic appeal of building facades.

In addition to mechanical innovations, the integration of advanced materials and technologies is pivotal in the evolution of responsive facades. For instance, electrochromic glass, which changes its optical properties in response to an electric field, offers a sophisticated means of regulating light and heat transmission (Alston, 2015). This technology allows for real-time adjustments to shading levels, thereby optimizing daylight penetration and reducing reliance on artificial lighting. The synergy between shading devices and responsive facade technologies is further enhanced by the incorporation of artificial intelligence and machine learning, which facilitate the optimization of multiple parameters, including illuminance and thermal comfort (Biloria, Makki & Abdollahzadeh, 2023).

The design of shading systems must also consider the interaction between indoor and outdoor environments. Research has shown that effective shading can lead to significant improvements in daylight quality and visual comfort within interior spaces. For example, studies comparing two-dimensional and three-dimensional shape-change facades have demonstrated that the latter provides superior performance in reducing glare and enhancing occupant comfort (Dabaj, Rahbar & Fakhr, 2022). This indicates that the morphological characteristics of shading devices are crucial in achieving desired lighting conditions while maintaining aesthetic coherence with the building's overall design.

Furthermore, the role of shading in enhancing thermal comfort cannot be overstated. Green facades, which incorporate vegetation as a shading strategy, have been shown to significantly reduce solar irradiation and improve microclimatic conditions around buildings. These systems not only provide aesthetic benefits but also contribute to energy savings by lowering cooling loads. The integration of vegetation into responsive facades exemplifies a holistic approach to architectural design, where ecological considerations are intertwined with technological advancements.

The performance of responsive facades is also influenced by their ability to adapt to varying climatic conditions throughout the year. For instance, the use of dynamic shading devices that respond to solar angles can optimize daylight access while minimizing heat gain during peak sunlight hours (Krüger et al., 2022). This adaptability is essential for maintaining comfortable indoor environments across different seasons and weather conditions. The implementation of such systems requires careful consideration of local climatic data and building orientation to ensure optimal performance.

In conclusion, the relationship between shading and responsive facades in architecture is characterized by a complex interplay of technology, ecology, and design. As buildings increasingly strive for sustainability and occupant comfort, the integration of advanced shading systems within responsive facades will play a pivotal role in shaping the future of architectural practice. The ongoing research and development in this field promise to yield innovative solutions that not only enhance the performance of buildings but also contribute to a more sustainable built environment (Figure 2).

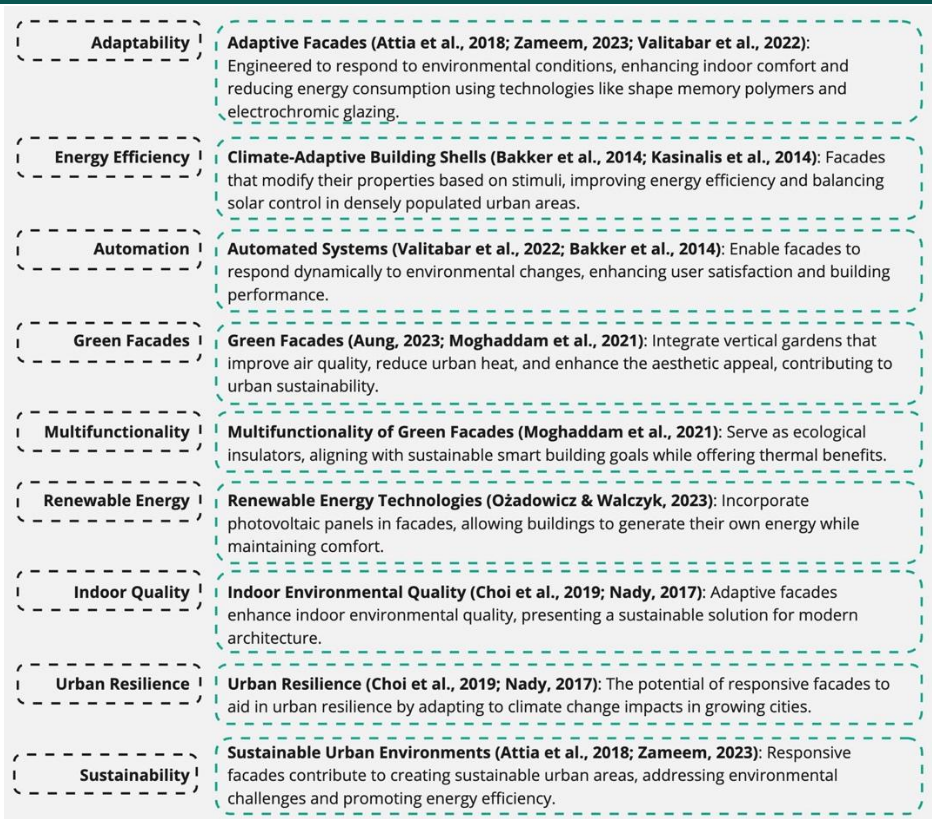

Figure 2. The Relationship Between Shading and Responsive Facades in Architecture.

4. The Disadvantages of Responsive Facades

Responsive facades, while offering innovative solutions for energy efficiency and occupant comfort, also present a range of disadvantages that must be critically examined. These disadvantages can be categorized into technical, economic, and user-related challenges, which collectively hinder the widespread adoption and effectiveness of responsive facade systems.

One of the primary technical challenges associated with responsive facades is their complexity. The integration of advanced materials and technologies often leads to intricate designs that require sophisticated control systems. For instance, the development of hybrid adaptive facades, which can respond to multiple environmental stimuli, necessitates a high level of technical expertise and precision in design and implementation (Khosromanesh, 2024). This complexity can result in increased maintenance requirements, as the systems may be more prone to malfunctions or require specialized knowledge for repairs (Gosztonyi, 2022). Furthermore, the performance of these facades can be inconsistent, particularly in varying climatic conditions, which may limit their effectiveness in providing the intended benefits (Hoces, Klein, Knaack & Auer, 2017).

Economic factors also play a significant role in the disadvantages of responsive facades. The initial costs associated with the design, materials, and installation of these systems can be prohibitively high, especially for new constructions or retrofitting existing buildings (Yitmen, Almusaed & Yücelgazi, 2021). The financial burden is compounded by the ongoing maintenance costs, which can escalate due to the need for specialized services and parts (Gosztonyi, 2022). Additionally, the return on investment for responsive facades may not be immediately apparent, as the energy savings and occupant comfort improvements can take time to materialize, leading to skepticism among stakeholders (Attia et al., 2018). This economic barrier can deter developers and building owners from pursuing responsive facade technologies, despite their potential benefits.

User-related challenges further complicate the implementation of responsive facades. The effectiveness of these systems often hinges on occupant interaction and preferences, which can be difficult to quantify and predict (Barra, Luna-Navarro, Prieto, Vásquez & Knaack, 2022). Research indicates that occupant responses to automated facade controls are not well understood, leading to potential dissatisfaction with the system's performance (Barra et al., 2022). Moreover, the reliance on user engagement for optimal operation can result in variability in performance, as not all occupants may utilize the system as intended (Gronostajska & Berbesz, 2018). This inconsistency can undermine the perceived value of responsive facades, as occupants may experience discomfort or dissatisfaction if the system does not meet their expectations (Giovanardi, 2024).

In addition to these challenges, there are also regulatory and compliance issues that can hinder the adoption of responsive facades. Stricter building codes and regulations aimed at reducing energy consumption can create additional hurdles for the integration of these systems. For example, the European Union's directive for nearly zero-energy buildings has pushed for more efficient designs, but the complexity of responsive facades can make compliance with these regulations more challenging (Hoces et al., 2017; Hoces, 2018). This regulatory landscape may discourage innovation in facade design, as developers may opt for simpler, more traditional solutions that are easier to implement and comply with.

Moreover, the environmental impact of responsive facades must also be considered. While these systems are often marketed as sustainable solutions, the production and disposal of advanced materials used in their construction can have significant ecological footprints (Alotaibi, 2023). The lifecycle assessment of responsive facades may reveal that the energy and resources consumed in their manufacture and maintenance could offset some of the environmental benefits they provide (Moschetti Homaei, Taveres-Cachat & Grynning, 2022). This paradox highlights the need for a more holistic approach to evaluating the sustainability of facade technologies.

In conclusion, while responsive facades offer promising advancements in building design, they are not without their disadvantages. Technical complexity, economic barriers, user-related challenges, regulatory compliance issues, and environmental impacts collectively pose significant obstacles to their widespread adoption. Addressing these challenges requires a concerted effort from architects, engineers, policymakers, and researchers to develop more effective, user-friendly, and economically viable solutions that can truly harness the potential of responsive facade technologies.

5. The Shading Problems of Responsive Facades in Manhattan

The shading problems of responsive facades in Manhattan present a complex interplay between architectural design, energy efficiency, and occupant comfort. As urban environments evolve, the need for adaptive façade systems that can dynamically respond to varying environmental conditions becomes increasingly critical. Traditional static façades often fail to adequately manage solar heat gain and daylight penetration, leading to increased energy consumption and discomfort for occupants (Biloria et al., 2023). In Manhattan, where high-rise buildings dominate the skyline, the integration of responsive shading devices is essential to optimize daylighting while minimizing glare and overheating risks (Attia, Bertrand, Cuchet, Yang & Tabadkani, 2022; Juaristi, Favoino, Gómez-Acebo & Monge-Barrio, 2021).

Recent studies highlight the effectiveness of adaptive façades, which utilize advanced materials and control systems to adjust their properties in real-time based on external conditions (Biloria et al., 2023; Brzezicki, 2021). These systems can enhance energy efficiency by reducing reliance on artificial lighting and cooling, thus addressing the urban heat island effect prevalent in densely populated areas like Manhattan (Mangkuto et al., 2021). However, the implementation of such technologies is not without challenges. The complexity of design, high initial costs, and the need for ongoing maintenance can deter their widespread adoption (d'Ambrosio, Matheou, Montuori & Nastri, 2021; Dakheel & Aoul, 2017). Moreover, the performance of these systems is highly context-dependent, necessitating thorough simulations and evaluations to ensure optimal functionality in specific urban settings (Juaristi et al., 2021; Attia et al., 2018).

The shading problems of responsive façades in Manhattan are multifaceted, influenced by the unique urban environment, climatic conditions, and architectural practices prevalent in the area. As the city continues to evolve, the integration of adaptive façades has become increasingly crucial to address energy efficiency, occupant comfort, and aesthetic considerations. This paper synthesizes current research on adaptive façades, focusing on their design, performance, and the challenges they face in the context of Manhattan's urban landscape.

Adaptive façades are defined as building envelopes that can adjust to varying environmental conditions, thereby enhancing energy efficiency and occupant comfort. These façades utilize advanced technologies, including embedded sensors and actuators, to respond dynamically to external stimuli such as sunlight, temperature, and wind (Attia et al., 2018). The ability of adaptive façades to modulate their properties in real-time allows for significant improvements in energy performance, with studies indicating that such systems can achieve up to 65% higher efficiency compared to traditional static façades (Biloria et al., 2023). This adaptability is particularly relevant in Manhattan, where high-rise buildings are subject to intense solar exposure and varying climatic conditions throughout the year.

One of the primary challenges associated with responsive façades is the complexity of their design and operation. While adaptive façades offer numerous benefits, they also require sophisticated control systems and maintenance protocols to function effectively (Juaristi et al., 2021). The integration of artificial intelligence and machine learning can enhance the performance of these systems by optimizing multiple parameters, such as illuminance and thermal comfort, based on real-time data (Biloria et al., 2023). However, the initial investment and ongoing operational costs can be significant, which may deter some developers from adopting these technologies in Manhattan's competitive real estate market.

The orientation of façades plays a critical role in their shading performance. Studies have shown that the effectiveness of shading devices varies significantly based on the façade's orientation relative to the sun's path (Lee, Han & Lee, 2017). In Manhattan, where buildings are often closely spaced, the interaction between adjacent structures can further complicate shading strategies. For instance, façades facing east and west are particularly vulnerable to glare and overheating due to direct sunlight during the morning and afternoon hours (Attia et al., 2022). Therefore, careful consideration of façade orientation and shading device design is essential to mitigate these issues and enhance occupant comfort.

Fixed and dynamic shading devices are two primary categories of shading solutions used in adaptive façades. Fixed shading devices, such as overhangs and fins, provide a consistent level of protection from solar gain but may not adapt to changing sunlight conditions throughout the day (Choi, Lee & Jo, 2017). However, the complexity of dynamic systems can lead to increased maintenance requirements and potential mechanical failures, which must be addressed to ensure their long-term viability in urban environments like Manhattan.

The integration of green façades and biophilic design elements is another innovative approach to addressing shading problems in Manhattan. Green façades, which incorporate vegetation into the building envelope, can provide natural shading while also improving air quality and enhancing the aesthetic appeal of urban environments (Kocurkova, 2023). Research has shown that green façades can significantly reduce solar heat gain and improve thermal comfort, making them a valuable addition to the architectural landscape of Manhattan (Kocurkova, 2023). However, the maintenance of living walls and the selection of appropriate plant species for the urban environment can pose challenges that need to be carefully managed.

Moreover, the impact of shading on daylight performance is a critical consideration in the design of responsive façades. Effective shading strategies can enhance daylight penetration while minimizing glare, thereby improving the overall quality of indoor environments (Dabaj et al., 2022). In Manhattan, where natural light is often limited by the density of buildings, optimizing daylight performance through thoughtful shading design is essential for creating healthy and productive workspaces (Lee et al., 2017).

The regulatory environment in Manhattan also influences the implementation of adaptive façades. Building codes and zoning regulations may impose restrictions on the use of certain materials or technologies, which can limit the potential for innovative shading solutions (Sherif, 2023). Furthermore, the historical context of many buildings in Manhattan necessitates a careful balance between modern design practices and preservation of architectural heritage. This challenge underscores the importance of collaboration between architects, engineers, and city planners to develop responsive façades that meet both aesthetic and functional requirements.

In conclusion, the shading problems of responsive façades in Manhattan are complex and multifaceted, requiring a nuanced understanding of architectural design, environmental conditions, and urban dynamics. While adaptive façades present significant opportunities for enhancing energy efficiency and occupant comfort, their successful implementation depends on addressing challenges related to design complexity, maintenance, and regulatory constraints. As Manhattan continues to evolve, the integration of innovative shading solutions will play a crucial role in shaping the future of its architectural landscape (Figure 3).

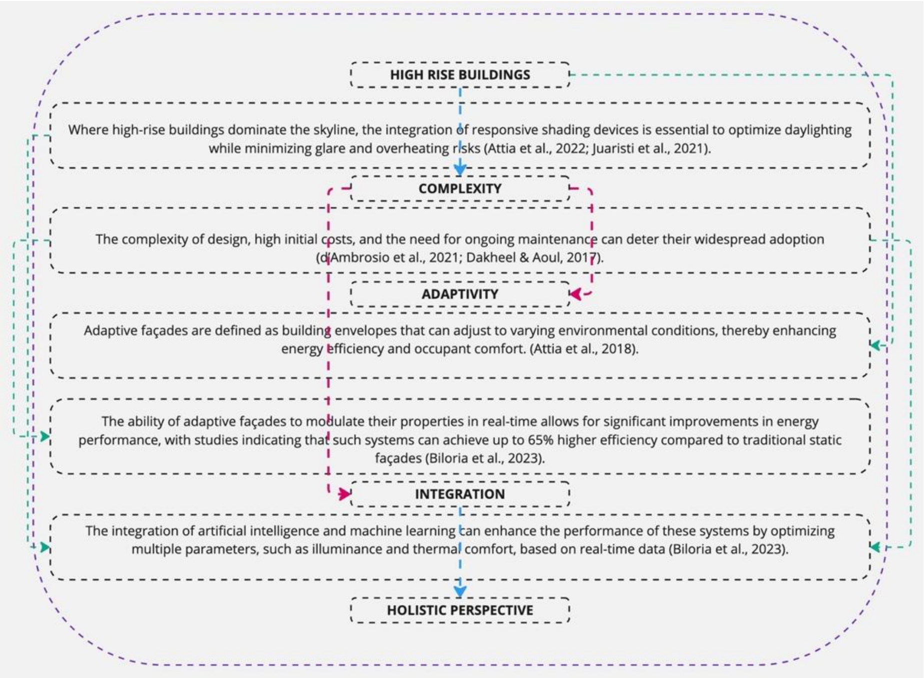

Figure 3. The Shading Problems of Responsive Facades in Manhattan.

6. Conclusion

The shading problems of responsive facades in Manhattan present a unique challenge due to the city's dense urban environment, varying climatic conditions, and the need for energy efficiency. Addressing these issues requires a multifaceted approach that incorporates adaptive shading technologies, design optimization, and an understanding of occupant comfort and energy performance.

Adaptive facades are increasingly recognized for their ability to respond dynamically to environmental changes, thus enhancing energy efficiency and occupant comfort. These systems can adjust to varying solar angles and weather conditions, effectively managing solar heat gain and glare while optimizing daylight penetration. For instance, Mangkuto et al. emphasize the importance of integrating adaptive shading systems that respond to indoor illuminance levels, suggesting that early design modeling can help mitigate costs associated with fully adaptive facades (Mangkuto et al., 2021). This aligns with the findings of Parsaee et al., who propose that adaptive panels could be designed with controllable openness and color variations to meet the specific daylighting needs of occupants, thereby improving thermal performance in extreme climates (Parsaee et al., 2020).

The performance assessment of adaptive facade systems is critical, as highlighted by Attia et al., who note that these systems must be designed to adapt to both short-term weather fluctuations and long-term seasonal changes (Attia et al., 2018). This adaptability is essential in a city like Manhattan, where the urban heat island effect and varying seasonal conditions can significantly impact energy consumption and indoor comfort levels. Moreover, the integration of dynamic shading devices can lead to substantial energy savings and improved user comfort, as indicated by Özdemir and Çakmak, who discuss the transition from static to dynamic facade designs in hot climates (Özdemir & Çakmak, 2022). This shift is particularly relevant in Manhattan, where summer temperatures can lead to increased cooling demands.

The potential for energy savings through adaptive facades is further supported by research from Attia et al., which compares various adaptive technologies and their effectiveness in regulating thermal and solar gains (Attia et al., 2022). The study underscores the growing demand for building envelopes that not only enhance energy efficiency but also provide a healthy indoor environment. This is particularly pertinent in Manhattan, where office buildings are under pressure to meet sustainability targets while ensuring occupant comfort.

Kinetic facades, which utilize dynamic shading devices, offer a promising solution for managing solar heat gain in urban settings. Choi et al. discuss the importance of calculating shaded fractions based on the movements of kinetic shading elements, which can significantly influence energy assessments and overall building performance (Choi et al., 2017). This approach is crucial for Manhattan's high-rise buildings, where the interplay of sunlight and building geometry can create complex shading challenges. The orientation of facades also plays a pivotal role in daylighting performance. Lee et al. found that the effectiveness of shading devices varies significantly with facade orientation, emphasizing the need for careful consideration of shading strategies based on the specific azimuth of the building (Lee et al., 2017). This is particularly relevant in Manhattan, where the orientation of buildings can lead to varying levels of daylight exposure and glare, necessitating tailored shading solutions.

In addition to adaptive and kinetic facades, the use of perforated shading screens has been explored as a means to enhance thermal performance while maintaining aesthetic appeal. Shedid et al. highlight the potential of integrating GRC (Glass Reinforced Concrete) shading screens into building designs to optimize daylighting and reduce energy consumption (Shedid, Tolba & Ezzeldin, 2021). This approach can be particularly beneficial in Manhattan, where the integration of innovative materials can contribute to the overall sustainability of high-rise developments.

The optimization of glazing technologies is another critical aspect of addressing shading problems. Favoino et al. demonstrate that adaptive glazing can significantly reduce energy consumption by responding to changing environmental conditions (Favoino, Overend & Jin, 2015). This adaptability is essential in Manhattan, where energy demands fluctuate throughout the day and across seasons. The integration of such technologies can lead to substantial reductions in cooling loads, as noted by Lee et al., who emphasize the importance of glare control and minimized solar heat gain in effective facade design (Lee Han & Lee, 2016).

Furthermore, the application of double skin facades (DSF) has been recognized as a viable strategy for enhancing thermal comfort and energy efficiency. Hendrik discusses how DSFs can effectively reduce heat ingress while providing additional insulation, thereby improving overall building performance (Hendrik, 2023). This is particularly relevant in Manhattan's urban context, where the thermal performance of facades is crucial for maintaining occupant comfort in both summer and winter months.

The incorporation of green facades also presents an innovative approach to managing shading and thermal performance. Convertino et al. explore the impact of leaf area index (LAI) on the thermal performance of green facades, suggesting that these systems can provide passive thermal control while enhancing the aesthetic value of buildings (Convertino, Schettini, Blanco, Bibbiani & Vox, 2022). In a densely populated area like Manhattan, where green space is limited, the integration of green facades can contribute to both environmental sustainability and improved urban aesthetics.

Simulation-based design approaches are essential for optimizing facade performance in high-rise buildings. As highlighted by Nady, the use of computational modeling can facilitate the design of dynamic facades that respond effectively to environmental conditions (Nady, 2017). This method allows architects and engineers to evaluate various design scenarios and their impact on energy efficiency and occupant comfort, which is particularly important in Manhattan's complex urban environment.

The implementation of shading devices must also consider occupant behavior and preferences. Research by Rajkumar and Priya indicates that well-designed shading strategies can significantly reduce energy demands in residential buildings, suggesting that similar principles can be applied to office environments in Manhattan (Rajkumar & Priya, 2023). Understanding how occupants interact with shading devices can inform the design of more effective and user-friendly systems.

In conclusion, addressing the shading problems of responsive facades in Manhattan requires a comprehensive approach that integrates adaptive technologies, design optimization, and occupant-centered strategies. By leveraging the insights from recent research on adaptive facades, kinetic shading systems, and innovative materials, architects and engineers can develop solutions that enhance energy efficiency, improve occupant comfort, and contribute to the sustainability of urban environments.

This book chapter complies with national and international research and publication ethics. Ethics committee approval was not required for this study.

Author Contributions and Conflict of Interest Declaration

This book chapter was written by a single author, and there are no conflicts of interest to declare.

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The Influence of Investment-led Urban Regeneration Policies on Sociality in the Context of Local and Global Governance: The Case of Liverpool

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1. Introduction

Urban areas are complex and constantly changing. This process of urban change is inevitable. Indeed, it can be observed that cities grow with the great benefits that come from their propensity for change and their complexity. As is well known, city governments constantly revise their strategies and policies in light of economic, social, and environmental continuity and new dynamics. It is true that many actors in the urban sphere deny this. However, the evolutionary forces of change create numerous opportunities and improve the quality of life, even if they react negatively. To rehabilitate existing cities destroyed and damaged during World War II, European cities were part of a rapid process of spatial transformation, particularly in terms of policymaking regarding large-scale urban rehabilitation and regeneration.

This transformation process was implemented at two fundamental levels. First, the economic infrastructure of cities, like evolution, required radical spatial restructuring. Second, the design and implementation of routes for new industrial facilities, their decentralization, and suburbanization efforts gained momentum. However, these spatial interventions led to land and building destruction, poor environmental conditions, labor losses, and severe social deprivation.

The emergence of physical decay in cities after the post-war period paved the way for the formation of a concept called urban regeneration, which took its place in urban planning. This concept describes three different paths of development. These are, first, the improvement of demolished areas and buildings and the maximum use of the remaining empty land, the second, the provision of new creative employment opportunities in places where there is a loss of labor, and the third, the development of the urban environment along with social problems. However, urban regeneration has evolved many times since the war began, with each era creating new urban problems. As a natural result of this, urban policies have been revised many times.

Following an economic downturn that led to abandonment, unemployment, and social deprivation, Liverpool underwent a series of urban regeneration initiatives in the early 1970s. These initiatives are carried out centrally by major urban development agencies and partnerships (on a national scale). Through these urban developments, the city gains national and local prestige and, through the marketing of its culture on a global scale, develops towards becoming a brand city. Thus, the city becomes ready for global organizations in terms of entrepreneurship and for economic development through economic entrepreneurship.

The entrepreneurial cities approach is concerned with transforming cities into businesses and stimulating economic competition. The pragmatic actions of these cities are expected to benefit all residents and all cities involved in this competition. Old welfare problems have given way to economic regeneration. In this way, new urban economic development will flourish.

Entrepreneurship in urban spatial development is primarily focused on capitalizing on economic development opportunities in local areas in need of urban regeneration (OECD, 2006).

Urban entrepreneurship, defined in the literature as "the process of creating value for citizens by bringing together unique combinations of public and private resources to exploit societal opportunities," aims to fundamentally change attitudes toward the private sector economy. Thus, public-private partnerships have become the dominant institutional structure for planning and emphasizing regeneration strategies. The adoption of urban entrepreneurship, the re-creation of urban enterprise zones and locations attractive due to their spatial characteristics, often overlooks local pressures and reflects the powerful disciplinary effects of intercity competition. Therefore, when urban competition becomes embedded in the spatial development logic of capitalism, it becomes virtually impossible for local governments to resist it (Harvey, 1989, 12).

Neoliberal regimes are political entities insensitive to narrow-mindedness and incompatibility. They target cities that are competitive but unable to achieve competitive urbanization. In such cities, national and transnational funding flows are based on economic potential and governance capacity rather than social needs (Peck & Tickell, 2002).

Large-scale urban projects are recognized as a means of marketing urban land, generating future urban and economic growth, and engaging in a competitive struggle to attract investment. These projects are also catalysts for urban and political change, fueling processes felt not only locally but also regionally, nationally, and internationally (Swyngedouw, Moulaert, and Rodriguez, 2002).

In many cities, urban regeneration reflects spatial characteristics such as strengthening the spatial expression of places, particularly in the central business district, shifting economic hierarchies and functions within the city, and creating new jobs and sectors. Such project-oriented urban interventions also foster a more ambitious, dynamic, and entrepreneurial style of urban management. Consequently, planners and local governments are adopting a more proactive and entrepreneurial approach aimed at helping private investors capitalize on these opportunities (Swyngedouw et al., 2002).

Large-scale urban projects aim to revitalize the local economy and include approaches aimed at improving the city's tax base for socio-spatial and economic restructuring. These projects are often presented as project-oriented, market-driven initiatives that replace statutory planning as the primary tool of urban intervention. The primary goal of these projects is to generate higher social and economic returns and revalue urban space. Urban rent and land speculation are central to such development strategies (Swyngedouw et al., 2002).

As a result of this redistribution of duties and responsibilities, regimes governing urban transformation are delegating their tasks to new institutions and organizations. These semi-private and autonomous organizations are competing with local and regional governments for greater flexibility and efficiency, replacing them as the initiators and managers of urban transformation. Thus, a new understanding of governance is being implemented that implies a better and more transparent connection between government and civil society. This system, which affects the built environment, may lack representation in participatory processes for specific groups. Furthermore, it involves individuals or organizations with diverse but allied perspectives in negotiations. Public-private partnerships are considered the ideal form of pluralistic governance (Swyngedouw et al., 2002).

Furthermore, the regeneration process in Liverpool was subject to intense central government intervention, with local government responsibility being shared among a number of agencies and organizations responsible for regeneration initiatives. This created challenges in managing urban regeneration (Couch, 2003; Tallon, 2010).

Cities are constrained by central government financial control. The changing nature of urban policy during the Thatcher government and the lack of money for capital projects created a new context for economic development. Despite the dominance of central government throughout the 1980s, local initiatives continued.

However, development projects were selected primarily on the basis of financial availability. Regeneration financing fostered new types of partnerships between local and regional, public and private, and local and regional interests (Newman & Thornley, 1996; 111-126).

In addition, the regeneration process in Liverpool has been subject to intense central government interventions, with local government responsibility divided among a number of agencies and organizations responsible for regeneration initiatives. This situation has caused difficulties in managing urban regeneration (Couch, 2003; Tallon, 2010).

Cities are limited by the financial control of the central government. The changing nature of urban policy under the Thatcher government and the lack of money for capital projects created a new context for economic development. Despite the dominance of the central government throughout the 1980s, local initiatives persisted.

However, development projects were selected mainly on the basis of financial availability. Regeneration finance has encouraged new types of partnership between local and regional, public and private, local and regional interests (Newman & Thornley; 1996; 111-126).

This study aims to reveal the economic dimension of global political regimes surrounding large-scale urban projects and the role of local public-private partnerships in project planning. It will also compare how large-scale urban projects encourage investment through neoliberal approaches and the roles assumed by local actors in urban projects.

However, due to the lack of transparency between government and civil society, this system affecting the built environment fails to represent the challenges faced by certain groups in coexistence and undermines social cohesion. Therefore, another aim of this study is to discuss the investor city in terms of design-oriented approaches, social inclusiveness, and sustainable communities.

1.1. Urban Regime Theory and Regeneration Policy Initiatives

In regeneration, there is an interaction between public and private actors responsible for governance. This interaction moves away from the influence and responsibility of central governments. Partnerships adopt a unique style of governance, "governing without government." In this form of governance, the market, the hierarchy of governance, and networks intermingle at the local, central, and global levels. In this understanding of governance, urban regime theory stands above the central and the local. Urban regime theory, based on networking, explains the division of labor between local governments and business elites in informal networks to generate economic growth. The question of the underdevelopment of urban regimes in Britain is a controversial one, and part of this debate is whether informal self-governance networks exist within urban regimes (Davies, 2002).

Political discourse in the 1980s presented the private sector as a key player in regeneration and positioned public-private partnerships as forward-looking spatial investments. As local government spending began to rise, declining English cities had no choice but to compete for private sector capital rather than central government support.

In urban regimes, dissent was carefully contained by local authorities and isolated from social pressures. Consequently, urban politics is considered a politics of exclusion, ignoring and marginalizing other voices. Regime politics are inevitable in large-scale urban projects, and unequal power relations pave the way for the marginalization and exclusion of groups considered "other," leading to projects purportedly aimed at improving the living conditions of urban citizens being dominated by the empty rhetoric of politicians.

In the 1980s, urban policy shifted its focus from the public to the private sector, driven by neoliberal policies such as public-private partnerships, privatization, deregulation, and centralization, as well as a revival of investment. This period, spanning 1979 to 1991, was known as the Thatcherite era. Social needs were seen as less important than business needs. The primary focus was on encouraging property-based entrepreneurship and the creativity of an investor culture. This period also explicitly rejected the Post-Keynesian welfare regime. Thatcherism became a doctrine for the modernization of the British economy by exposing the country's industry, cities, and people to the challenges of international competition (Tallon, 2010; 43-45). The political vision imposed on the urban regime during this period paved the way for the emergence of numerous social inequalities.

After 18 years of Conservative rule, New Labour's urban policy movement gained momentum in terms of implementing urban policies with economic and social dimensions, which were referred to as "urban renaissance" (Tallon, 2010; 78). The vision of New Labour policy was to combat social exclusion, the root of multiple deprivation in cities. Recent government urban policy initiatives documented a new urban policy under the name of urban renaissance, focusing on urban sustainability, gentrification, and the call for people to return to the city (Lees, 2003; 61). Thus, the Urban White Paper, enacted in 1977, was updated in 2000, and the Urban Duty Implementation was mandated by the government through the Urban White Paper, which was prepared to include poor people and neglected neighbourhoods in a holistic planning process (Lees, 2003; 61-63).

In this context, the Urban Task Force (1999) chaired by Richard Rogers, proposed practical solutions for sustainable regeneration and identified the consequences of urban decline, seeking solutions. In this context, the report Towards an Urban Renaissance was published in 1999. The report encouraged design excellence and the redevelopment of former industrial, residential, and commercial areas, and gave rise to a new movement addressing social injustices, including poverty and racial discrimination (Tallon, 2010; 79). This should be considered an approach that sought to address inequalities arising from urban regime theory at the local level.

In contrast to the urban regeneration of Conservative power, New Labour’s urban renaissance is comprehensive and intensive. It means considering both the liberalisation of the right and the social justice of the left (Lees, 2003; 66-67).

When the New Labour parliament came to power in 1997 under Tony Blair's leadership, the parliament implemented third way policies, balancing competitive individualism and emancipation within social justice and community participation. In addition, the government sought to revitalise local democracy by emphasising the concept of 'citizenship' and a dynamic local leadership stance that referred to a more participatory society and wider public deliberation (Punter, 2010; 3).

As part of its urban renaissance agenda, the government published a series of reports, the main themes of which were population, economic competitiveness and performance, livability, social cohesion and governance. It delivered competitiveness in Britain's 'core cities', such as Birmingham, Bristol, Leeds, Liverpool, Manchester, Newcastle, Nottingham and Sheffield (Tallon, 2010; 80-81).

1.2. Policy Developments and Partnerships in Liverpool

Over the last three decades Liverpool, along with other UK and European cities, has undergone major restructuring due to its economic decline.

In the 1960s, social development played an important role in the implementation of policies. The Urban Programme was launched in 1968 and consisted of short-term funds to support local initiatives in the city centre (Couch, 2003; 34).

By the late 1970s, the rate of inner-city deprivation had risen significantly and the government was convinced that the underlying deprivation was economic and physical rather than social. The partnerships established to address this problem were under the auspices of Thatcher's Conservative

Party. The lack of local initiatives was notable throughout this period (Couch, 2003; 34-35).

Moreover, during the 1960s and 1970s, the City Council engaged in a large-scale slum clearance program, to the extent that a large number of housing stocks emerged on the periphery of the city. Due to concerns about rising costs and falling populations, the program was terminated in the mid-1970s (Couch et al. 2005; 123).

During the 1980s, 'English regeneration policy placed great emphasis on supporting local economic development by increasing the supply of land and buildings in inner urban areas' (Couch, 2003; 34). By the end of the decade there was increasing criticism that local authorities and local initiatives were almost completely neglecting local knowledge of the area. Therefore, the first response of the government was the introduction of the City Challenge: 'a programme allowing local authorities to lead local partnerships with central government funding to support regeneration projects. City Challenge was subsequently replaced by the Single Regeneration Bugdet, with 21 different funding streams, and the work of a number of agencies was merged into a single organisation: English Partnerships (Couch, 2003; 35). Furthermore, "the approval of the Merseyside Structure Plan and the Merseyside Green Belt Local Plan in the early 1980s led to a strengthening of urban regeneration policies and stronger restrictions than hitherto on building outside the existing urban area" (Couch et al. 2005; 123).

Under New Labour, urban regeneration policies were re-established with the Urban Task Force's Towards an Urban Renaissance and Urban White Paper. "One of the most significant initiatives has been the establishment of urban regeneration companies, intended to be single-purpose development agencies responsible for managing and coordinating the regeneration of specific areas” (Couch, 2003; 35-37). Liverpool Vision is a typical example of one such company.

In addition, A National Strategy for Neighbourhood Regeneration was established in 2001 and has aimed to improve living conditions in the most deprived neighbourhoods. In this context, local strategic partnerships have been responsible for local neighbourhood regeneration strategies, supported from the ground up by the Neighbourhood Regeneration Fund. The New Deal for Communities (NDC) programme is also responsible for funding deprived neighbourhoods. Kensington in Liverpool is one of the places that received NDC funding (Couch, 2003; 37).

Liverpool has faced a number of urban regeneration initiatives since the 1980s and a number of partnerships have played a key role in their implementation. Some of these partnerships will now be explored.

The first, the Merseyside Development Corporation (MDC), established in 1981, expanded its boundaries in 1988. The MDC’s activities were carried out over three distinct periods. The first, 1981–1988, involved a reorientation of the First Development Strategy to address the harsh economic and political realities of its area of operations. The second, a short period between 1988 and 1991, saw attempts to expand the partnership’s boundaries and to accommodate populations working and living within its boundaries. The third period between 1992 and 1998 saw both the status of urban policy changes and an agreement with the European Union’s Structural Fund, such as the funding of Objective One (Meegan, 1999;72).

Secondly, the Rope Walks Partnership, established in 1997, has been responsible for the regeneration of public spaces in East Liverpool, the Duke and Bold Street regeneration, as well as creating cultural industries and stimulating the night-time economy (Couch, 2003; 46).

The third, Liverpool Vision, was established in response to the call of the Urban Task Force in Towards an Urban Renaissance. The company set out a series of initiatives to elevate Liverpool to the 'big picture'. These were long-term solutions and included creating a competitive and 21st century economy, developing a strong workforce and inclusive communities, providing a high-quality safe environment, highlighting the city's rich historical character, attracting tourists, developing tourism development capabilities and creating high quality lifestyles, and improving the city's European image. In short, Liverpool Vision adhered to the sustainable design policies of the Urban Task Force (Liverpool Vision, 2008; 19).

Fourth, Urban Splash, which was founded in 1993 and is responsible for physical renovations, is a company that operates in Manchester and Liverpool, and recycles old buildings and uses modern architectural techniques while doing so. In short, Urban Splash is a company that buys and develops properties that need to be renovated. For the Concert Square, which it is responsible for renovating, it serves as an architect and developer by preserving the best of the existing structure and including contemporary elements (Bloxham, 2001; 67-72).

Other partnerships and companies include City Challenge: Liverpool City Centre East, responsible for historic environmental protection, The Eldonians and North Liverpool Partnership, responsible for blighted environments and housing development (Colquhoun, 1995; 89; Couch, 2003).

2. Material and Method

The study is addressed through various books, reports, and articles. A literature review on urban regeneration policies in Britain is conducted through the work of Tallon, Couch, and Roberts. These three authors were chosen because they have extensive urban regeneration studies specific to Britain and offer highly illustrative schematic approaches. Furthermore, Couch's work on Liverpool is known to have contributed significantly to the literature. Tallon and Roberts are known for their significant analyses, particularly regarding public-private partnerships in regeneration. They also conducted detailed analyses of the evolution of urban regeneration.

In Liverpool, a British city where urban regeneration has been implemented, the policies associated with regeneration are addressed, particularly through the work of Biddulph, and the evaluation of major physical interventions, particularly in terms of design-led urban renewal, social participation and sustainable communities, through the work of Bell and Jayne, Roberts, Ginsburg, Lees, Bell and Lane and Raco respectively. The study employed qualitative content analysis, largely conceptualizing and schematizing the topics discussed. The figure below clarifies the phenomenon of governance in urban regeneration being positioned above the central and local levels through urban regime analysis (Figure 1).

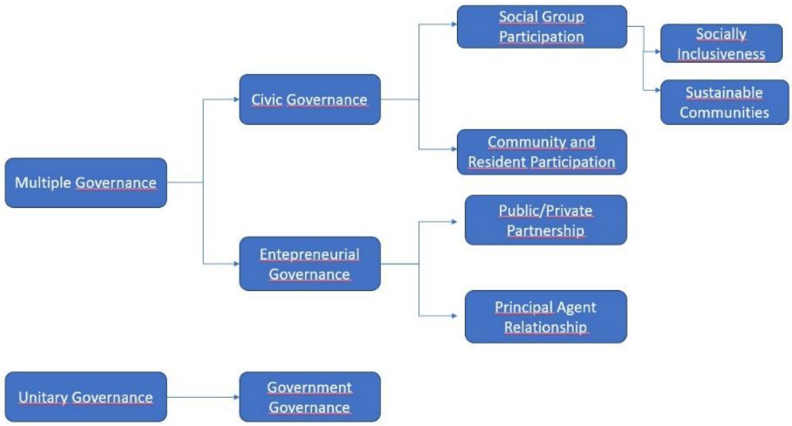

Figure 1. The Categories of Urban Regeneration Governance Modes (Xie, Liu & Zhuang, 2021).

The table below examines the governance aspects of urban regeneration in Britain, both through public-private partnerships led by local and central governments. The study identifies the institutions and businesses involved in creating large-scale urban projects in Liverpool, as well as the national and local project agencies (Table 1).

Table 1. Governance Aspects of Urban Regeneration in Britain (This table was prepared from Yunus Emre Sarıkaya's MA Dissertation).

	Public Sector	**Private Sector**	**Public/Private Sectors**
National Level	-Development agencies -Urban Development Corporations -Inner City Task Forces/City Action Teams -Single Regeneration Bugdet -English Partnerships	-Urban Regeneration Development Consortia -Umbrella Organizations	Merseyside Development Corporation Liverpool Vision
Local Level	-Enterprise Boards -Local Authority Economic Development -City Council	-Urban Splash -The Eldonians	-Enterprise Partnerships -Development partnerships

The research is enriched by a literature review examining the work of the aforementioned experts. The issues arising during and after the implementation phase of urban projects in Liverpool are addressed from the perspective of design-led urban regeneration, social inclusion, and sustainable communities.

3. Findings and Discussion

In the wake of neoliberalism, many cities in Europe began to expand. This brought new approaches and decisions to urban planning and regeneration agendas. However, while these practices partially addressed issues of economic prosperity and competitiveness, they were criticized for ignoring certain social norms and taking too many physical assumptions into account. This section examines design-led urban regeneration, social inclusion, and sustainable communities, particularly in terms of whether projects addressed social problems, created jobs for everyone, and adhered to the Urban Task Force's development principles.

It is clear that the New Labour government's initial urban renaissance aimed to improve poor people and neglected neighborhoods, unlike Thatcher's Conservative government, which resulted in the devastating consequences of neoliberalism for the poor.

In implementing third-way policies, New Labour sought to integrate the left with social justice and community participation, and the right with competitive individual approaches and liberation.

However, when we focus on large-scale urban projects in Liverpool, we find that integrated urban design projects, particularly those focusing on the cultural industry, cultural districts, and specific streets, do not support third-way policies due to the neglect of poorer segments of society in participatory processes. It should also be noted that this urban design is far from ideal for the middle class, which encompasses a large segment of society.

Design-led regeneration was implemented in Britain in 1999 under the New Labour Party's policy. Despite highlighting design-related studies and practices, it was criticized by experts for neglecting multiculturalism and urban citizenship (Punter, 2007; 376). This led to urban design becoming a planning policy and practice in the later years of the Conservative government and fully adopted by the New Labour government in 1997 (Roberts, 2009; 491).

One of the most distinctive features of the post-industrial economy is the transition from cities to a competitive global arena. Design plays a significant role in this competition. However, what constitutes successful design-led urban regeneration, sustainable design policy, and design economics remains unclear (Bell & Jayne, 2003, 121). The central argument is that the solutions offered by design-led approaches to societal problems are being overshadowed by global competition and rivalry.

Finally, and most importantly, all these initiatives offer an opportunity to examine different aspects of design-led urban regeneration. However, it is important to note that the projects are not fully considered successful because they do not adequately reflect the power of a holistic, strategic, and integrated design policy that addresses all aspects of urban problems (Bell & Jayne, 2003, p. 127).

They offer different perspectives on how design-led urban regeneration can stem from a design culture. However, these investment, innovation, and creativity issues appeal more to post-industrial employers, consumers, and tourists than to the urban community. These economic initiatives are directly linked to the entrepreneurial styles and lifestyles of the central urban area and to post-industrial cultures of production and consumption. Consequently, this connection is used to create new production and consumption chains, networks, and cultures within local and regional economies. However, to achieve success in design-led urban regeneration, economic, socio-spatial, and cultural components must be considered (Bell & Jayne, 2003; 132-133). In this context, although the Liverpool One project, in particular, was criticized by the middle class for its removal of anti-social elements, it is considered the most successful design-led approach in terms of restoring the city to its original physical fabric with a more open street system, transforming it into a well-connected and permeable space (Biddulph, 2011; 85-89, Adams & Tiesdell, 2013; 21). Similarly, the Rope Walks development project, which significantly increased property values in the area, could be criticized for providing property-led regeneration and not for being a socially inclusive development. Another property- and rent-focused project is the Fourth Grace project, which was cancelled due to its high cost. Another reason for the project's cancellation was its failure to develop a common language of public space (Biddulph, 2011).

Secondly, the concept of social inclusion in urban regeneration policies is noteworthy as a topic worthy of discussion.

Social regeneration dominated the policy agenda in the late 1960s and early 1970s. However, it almost disappeared during the Thatcherite welfare crisis. However, after New Labour came to power, the social regeneration agenda was revisited, despite some criticism. In this section, we will examine the term "social" in the regeneration policy agenda (Ginsburg, 1999, 55).

It is true that urban regeneration policies emphasize physical and commercial redevelopment but neglect the social fabric. For these reasons, social regeneration policies address problems of social exclusion. These policies include:

- Developing social street furniture;
- Increasing participation and community empowerment;
- Investing in civil society, social capital, and social trust;
- Considering the needs of subcultural groups.

In the 1960s, central urban areas were incorporated into minority neighborhoods (Lees, 2008). Thus, the central urban area became the target of government efforts to rediscover poverty because the government believed that social problems and deprivation were spatially induced (Ginsburg, 1999, 57).

Another aspect of urban regeneration and its policies in Britain that needs to be discussed is the creation of sustainable communities.

The sustainable communities approach has become a British urban policy that integrates people from different segments of society and combats social exclusion (Gullino, 2008; 127-129). Sustainable communities are a relatively new concept that aligns with the principles outlined in The Urban Task Force (UTF) and acts as a key driver of social, environmental and economic well-being (Bell & Lane, 2009; 647).

However, there are some contradictions between the UTF and sustainable communities policy; in fact, the UTF has weakened its stance on urban regeneration while focusing on sustainable communities. In the context of sustainability, planning policy has facilitated the creation of dynamic, vibrant towns and cities, and more holistic and all-encompassing restructuring has gained importance. The sustainable communities approach serves as an interface between relational citizenship and safe design (Raco, 2007, pp. 305-306).

The UTF report paid little attention to the community building proposed by the New Labour government, but in the 2000s, a new platform was created where communities could decide their own socio-economic future through community-to-community partnerships. The sustainable communities approach has been an important concept in urban citizenship and in building safer, more quality-of-life places (Raco, 2007, 308-309).

The concept of sustainable communities represents an important interface between urban sustainability, urban design, and governance in urban regeneration. Sustainable communities are also an approach that fosters a balanced and persistent increase in economic vitality, social equity, and civil democracy, thereby fostering a high quality of life and strengthening citizenship rights through the additional responsibility it envisions. Another perspective that dominates the literature on sustainable communities is the urban design approach of planners and architects. It emerges as a crucial approach for revitalizing declining local economies, managing urban growth, and balancing demand for transportation, housing, jobs, environmental quality, and social services (Ercan, 2020; 28-29).

4. Conclusion and Suggestions

To conclude, it is worth noting that urban policies at both national and international levels must be integrated with urban regeneration initiatives to legislatively address urban problems. The dominant forces shaping and transforming cities in Liverpool's regeneration are the neoliberal economic environment, the entrepreneurial city, and the use of state power to promote business and finance. Investments in cities and their transformations are largely detached from social phenomena and oriented toward businesses. Neoliberalism's financialization, with its emphasis on profit, property, and the built environment, has suppressed diverse human experiences and social phenomena (Speake & Pentaraki, 2017).

In Britain, the objectives of urban regeneration are much more closely linked to economic considerations, or equivalently, to the transformation of social, cultural, physical, and environmental assets into economic assets. Indeed, as previously noted in the context of Liverpool in the 1960s, social development policies superseded economic and physical development in the 1970s, but the Liverpool Vision Partnership was crucial in aligning with the UTF report "Towards an Urban Renaissance." The partnerships, which played a key role in Liverpool's development, had as their primary objective the prevention of unemployment and the provision of housing and social inclusion. However, it is also important to highlight the policies imposed by the government on the partnerships to encourage the transformation of social benefits into economic benefits. In this case, while some projects, such as Liverpool One, were successful, they did not meet the needs of all segments of society, to the extent that the project led to social exclusion among some marginalized groups. Furthermore, despite playing a key role in Liverpool's regeneration and neglecting social inclusion, the extent to which Ropewalks increased property values has been criticized.

However, according to Tallon, the implementation of regeneration policies is problematic due to a lack of long-term strategic approaches and a much greater emphasis on property-led regeneration and urban design. Indeed, the Merseyside Development Authority's focus on project-based implementation, coupled with a lack of political oversight and synchronization of implementation with other local institutions, is evident. However, it should be noted that urban design has the potential to alleviate social problems by helping to improve certain social conditions, such as unemployment, and by fostering urban entrepreneurship and competitiveness, while some evidence suggests that it neglects multiculturalism and urban citizenship. Fundamentally, design-led urban regeneration can create its own culture, consumerism (through urban entrepreneurship), innovation, and creativity.

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Nature-Based Integration of Architecture and Landscape: Ecological Design for Climate-Responsive Cities

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1. Introduction

Climate change, the most defining environmental issue of the 21st century, has become a global transformation area that redefines the form of urbanization, architectural production processes, and landscape planning. Increasing greenhouse gas emissions, rapid urbanization, increased surface impermeability, and the fragmentation of natural ecosystems are causing microclimatic imbalances, especially in large cities (Santamouris, 2024). In this context, the urban heat island effect, the irregularity of flood and drought cycles, air quality deterioration, and loss of biodiversity have created a new ecological agenda that requires not only environmental engineering but also architecture and landscape disciplines to directly produce solutions (Kumar et al., 2025).

Traditional architecture and planning approaches have long addressed climate issues at the level of spatial configuration and structural insulation, adopting a "protective" strategy that aims to isolate the building itself from environmental impacts. However, today, the Nature-Based Solutions (NbS) approach is replacing this understanding with an integrative design paradigm that prioritizes ecological integrity. This paradigm positions architectural structures and landscape systems not as opposites, but as dynamic ecological components in mutual interaction (Sommese et al., 2024). Thus, architecture is being redefined not only as an aesthetic and functional discipline, but also as one with the potential to produce ecosystem services.

A significant portion of microclimatic imbalances in cities is related to low surface albedo, high impervious material ratios, and low vegetation coverage (Wong & Jusuf, 2023). Heat-storing surfaces such as concrete, asphalt, and glass absorb solar radiation throughout the day, causing heat to radiate at night, which intensifies the urban heat island (UHI) effect. Research shows that green infrastructure applications (e.g., rooftop gardens, permeable pavements, rain gardens, and green corridors) can reduce surface temperatures by 2–5 °C, contribute to microclimate balance through evapotranspiration, and improve air quality parameters (Santamouris, 2024; Hu et al., 2024). Therefore, architectural design and landscape planning must be evaluated within a holistic strategy to achieve climate comfort and energy efficiency goals.

At this point, coordination between architecture and landscape design means ensuring functional and ecological synchronization rather than merely formal harmony. The form, orientation, configuration of shading elements, and level of permeability of the building envelope must be considered in conjunction with the vegetative layering, water cycle management, and micro-topography in landscape design. For example, vegetated roof and façade systems are important not only for energy efficiency but also for producing ecosystem services such as carbon sequestration, particulate filtration, and heat flow regulation (Wong & Jusuf, 2023). Similarly, blue-green infrastructure components—rainwater channels, bio-swales, wetlands, and permeable surfaces—reduce flood risk while increasing water reuse and supporting ecosystem integrity (Kumar et al., 2025).

Microclimate-focused architecture-landscape coordination is not only a matter of the physical environment but also implies the spatial organization of biophysical processes. Shading, wind direction, evaporation, and control of local humidity balance are fundamental components of sustainable urban living quality in terms of both human thermal comfort and plant physiology (Hu et al., 2024). Adaptive and flexible design approaches developed in this direction are giving rise to a new design culture in which architectural forms can respond dynamically to climatic variability and integrate the energy cycle with natural processes.

This new model of interaction between architecture and landscape is not limited to reducing the heat island effect or providing flood management. It also represents a transformation that increases urban ecosystem services, supports biodiversity, and provides indirect benefits to human health. Today, sustainable urbanization policies are evolving beyond the concept of "green buildings" to an ecosystem-based urban resilience approach (Cook et al., 2025). According to this approach, buildings and landscapes are no longer separate design categories; they are integrated systems with common climatic, ecological, and aesthetic goals.

This study aims to comprehensively address nature-based and microclimate-sensitive design principles based on collaboration between the disciplines of architecture and landscape architecture in the face of environmental threats posed by climate change. In this regard, fundamental urban climate problems such as the heat island effect, flood risk, and drought will be discussed within the framework of green infrastructure, architectural shield systems, and adaptive design approaches. The ultimate goal is to highlight the strategic role of architecture-landscape coordination in the formation of sustainable, flexible, and resilient cities.

2. Urban Heat Island Effect and Landscape-Architecture Interaction

One of the most prominent reflections of global climate change on cities is the urban heat island (UHI) phenomenon. UHI is characterized by higher temperatures in city centers compared to surrounding rural areas, with this difference typically ranging between 2–7 °C (Santamouris, 2024). The main causes of this phenomenon include an increase in impervious surfaces, loss of vegetation cover, use of heat-absorbing building materials, dense construction, and reduced air circulation. Rising surface temperatures not only reduce thermal comfort but also increase energy consumption, adversely affect human health, and disrupt the balance of ecological processes (Kumar et al., 2025).

Recent studies have shown that addressing architectural form and landscape systems together is extremely effective in reducing the UHI effect. Nature-based design elements such as green roof systems, green facades, permeable surfaces, and water features provide microclimatic cooling through evapotranspiration, shading, and heat reflection (Wong & Jusuf, 2023). Green roofs, in particular, reduce surface temperatures by an average of 3–4 °C and improve indoor comfort by reducing thermal flow. This effect also has positive results on the overall thermal balance of the city; it has been reported to reduce energy consumption by up to 20% during the summer months (Santamouris, 2024).

Landscape planning functions not only as an aesthetic element in this process but also as an ecological buffer system (Tuğluer & Çakır, 2021). Green corridors, park systems, biological ditches, and rain gardens stabilize the microclimate by regulating surface temperature and maintaining moisture balance. Furthermore, these elements contribute to ecosystem services such as air quality, particulate filtration, and carbon sequestration (Hu et al., 2024). The continuity of the landscape fabric enhances air circulation by supporting the effective functioning of wind-directing channels and shading areas. Thus, thermal comfort and energy efficiency are achieved at both the building and city scales.

From an architectural perspective, factors such as building form, shell color, surface roughness, orientation, and material selection are directly related to UHI dynamics. Light-colored and highly reflective surface materials (high-albedo materials) reduce surface temperature by reflecting part of the solar radiation, while facades with low emissivity limit the transfer of thermal load to the interior (Santamouris, 2024). Architectural massing and the ratio of building height to street width (H/W) are also key morphological factors determining airflow; an optimal thermal balance is achieved when this ratio is between 0.5 and 1 (Wong & Jusuf, 2023).

The integrated planning of landscape and architecture not only reduces heat but also increases user comfort through psychological and biophilic effects. The visual presence of natural surfaces and green textures reduces stress indicators in human physiology and enhances microclimatic satisfaction (Raza et al., 2024). Therefore, in the architectural design process, landscape should be considered not merely as an environmental addition but as a structural climatic regulator.

Reducing the UHI effect requires understanding the complex relationships between building envelope performance, energy efficiency, materials science, and biophysical processes. Current research shows that when these relationships are evaluated using simulation and data-driven modeling techniques (e.g., ENVI-met, CFD analyses), microclimate design becomes measurable (Kumar et al., 2025). Thus, architecture is repositioning itself as a system that provides not only passive protection but also active climate regulation.

Consequently, coordinating architecture and landscape disciplines in managing the urban heat island effect requires a multi-layered, nature-based, and ecosystem service-oriented approach. Restoring thermal energy balance is possible not only through technical solutions but also through the synergy between landscape ecology, architectural morphology, and microclimatic analysis. Therefore, the most fundamental strategy for sustainable cities of the future is the simultaneous design of architectural form and ecological landscape texture.

3. Architectural-Landscape Solutions in Flood and Rainwater Management

One of the most significant urban-scale effects of climate change is the irregularity in rainfall patterns and the resulting increase in sudden flooding events. Increased surface impermeability, intensive development, and the reduction of natural soil areas cause most of the rainfall to turn into surface runoff without seeping into the ground. This situation both increases the risk of flooding and causes hydrogeological imbalance by disrupting the urban water cycle (Li et al., 2024). In this context, architecture and landscape planning are developing nature-based solutions (NbS) that focus not only on removing water but also on retaining, filtering, and reusing it (Sommese et al., 2024).

Traditional urban infrastructure systems rely on a gray infrastructure approach that aims to remove rainwater as quickly as possible through channels. However, the “blue-green infrastructure” (BGI) model developed in recent years treats water not as a threat but as a resource and integrates it into the urban fabric. This approach incorporates landscape-based systems such as rain gardens, bioswales, permeable surfaces, green roofs, and water collection basins (Kumar et al., 2025). These systems slow down surface runoff of rainwater, enabling filtration, replenishing groundwater, and producing ecosystem services.

The discipline of architecture supports the sustainability of the hydrological cycle by transferring these infrastructure forms to the building scale. For example, green roofs can retain 50–80% of rainfall; green facade systems delay rainwater runoff, reducing the load on drainage systems (Berardi & Ghaffarianhoseini, 2024). Rainwater harvesting systems create resource efficiency by enabling the reuse of water collected at the building scale for landscape irrigation or in gray water systems. In this way, architectural structures become components that actively contribute to the water cycle, rather than merely consuming water.

From a landscape ecology perspective, the most effective strategy in rainwater management is to increase soil permeability and reestablish hydrological connectivity. Permeable surfaces (permeable paving, gravel surfaces, porous concrete) reduce surface runoff, while plant root structures enhance the infiltration capacity of the soil (Li et al., 2024). Furthermore, micro-topography modifications reduce flood pressure by allowing rainwater to be temporarily stored in low-lying areas. This approach aligns with the principles of direct ecosystem-based adaptation (EbA) (Cook et al., 2025).

Sustainable Urban Drainage Systems (SuDS) implemented at the city level bring architecture and landscape design together on a common planning platform. SuDS systems are based on the principles of water retention, delay, filtration, and reuse at the source (Hu et al., 2024). These systems also create habitats that increase biodiversity; wetland plants (e.g., *Typha latifolia, Phragmites australis*) provide water filtration and serve as microhabitats. Thus, flood management becomes part of an ecological restoration approach, not just engineering.

The coordinated implementation of architectural design and landscape planning is critical for climate resilience. Case studies show that connecting architectural structures to landscape drainage systems in cities such as Singapore, Copenhagen, and Rotterdam has reduced flood risk by up to 30% (Wong & Jusuf, 2023). In such integrated applications, building base levels, rainwater storage volumes, and landscape slopes are designed together. The resulting system constitutes an important model in terms of both adaptation to climate change and the restoration of the urban water cycle to its natural state.

Current literature also highlights the reciprocal relationship between stormwater management and microclimate. Retaining rainfall within the landscape increases surface evaporation, creating a local cooling effect (Berardi & Ghaffarianhoseini, 2024). This reduces the UHI effect while also contributing to the carbon cycle through increased plant evapotranspiration. Thus, water becomes an active architectural component that not only reduces the threat of flooding but also regulates the microclimate.

Consequently, architecture-landscape coordination in flood and stormwater management brings together the concepts of ecological engineering, architectural aesthetics, and hydrological efficiency on the same ground. The water-focused components of nature-based design represent an innovative infrastructure paradigm for future cities that both increases climate adaptation capacity and diversifies ecosystem services.

4.The Role of Green Infrastructure as an "Architectural Shield"

The increasing effects of global climate change have made it imperative for the disciplines of architecture and landscape architecture to take on not only the role of shaping spaces, but also that of environmental regulation and protection. In this context, the concept of green infrastructure (GI) is defined as a multifunctional system that creates an ecological protection layer between the building envelope, the ground, and the surrounding landscape (Sommese et al., 2024). Green infrastructure acts as an "architectural shield" against environmental impacts such as heat, wind, water, dust, and noise, providing both structural and biotic resilience (Kumar et al., 2025).

4.1. Green Roof and Facade Systems: Energy and Thermal Comfort Balance

Green roofs and vegetated facade systems are among the most effective architectural tools for microclimate regulation. Thanks to the effects of plant evapotranspiration, shading, and surface thermal reflection (albedo), they can reduce roof surface temperatures by an average of 20–25 °C compared to traditional systems (Berardi & Ghaffarianhoseini, 2024). These systems also reduce the heat transfer coefficient (U-value), lowering cooling energy requirements in summer and heating energy requirements in winter.

Research shows that green roofs reduce annual energy consumption by 15–25% and improve environmental performance through carbon sequestration and particulate filtration (Kumar et al., 2025). Living wall systems, on the other hand, increase surface albedo, particularly on south-facing facades, thereby increasing heat flow resistance and reducing noise emissions by 8–10 dB (Li et al., 2024). In this respect, green surfaces are considered not only visually aesthetic but also a "natural shield" that supports the biophysical resilience of the building envelope.

4.2. Green Corridors, Buffer Zones, and Wind Regimes

When considered at the urban scale, green corridors and buffer zones play a key role in reducing the urban heat island effect, regulating airflow, and maintaining moisture balance. Linear tree-lined axes create cooling channels by enhancing heat and moisture transport; broad-leaved plants provide shade, while coniferous species support microclimate balance through their windbreak effect (Wong & Jusuf, 2023). In particular, the strategic relationship established between wind-directing corridors and the positioning of buildings increases natural ventilation opportunities by reducing thermal loading (Hu et al., 2024).

Buffer zones act as biological filters between building groups and high-traffic corridors or industrial areas. These areas, consisting of layers of trees and shrubs, trap air pollutants ($PM_{2.5}$, NOx), reduce noise emissions, and also create aesthetic and psychological comfort (Raza et al., 2024). Thus, the landscape becomes not only an environmental element of the urban fabric but also a microclimatic defense mechanism.

4.3. Water Management, Microclimate, and Adaptive Shield Systems

The "architectural shield" role of green infrastructure is not limited to thermal energy; it is also functional in terms of water cycle management. Roof gardens, working in conjunction with rainwater harvesting systems, enhance the evaporation-condensation cycle, thereby lowering air temperature while increasing humidity. Blue-green infrastructure systems buffer hydrological shocks by temporarily storing water during floods and cool the environment through evaporation during dry periods (Li et al., 2024). These mechanisms become an active part of the architectural structure in adapting to climate change.

Recent studies show that dynamic “adaptive shield” solutions can be developed by integrating green infrastructure elements with sensor systems based on digital climate data (Cook et al., 2025). In these systems, data obtained from soil moisture, air temperature, and solar radiation sensors automatically regulate irrigation and shading mechanisms, creating smart ecological shells. When combined with biomimetic design principles, this approach ensures that green infrastructure becomes not only a passive but also a reactive layer of defense.

4.4. Ecological and Socio-Spatial Benefits

Green infrastructure systems provide physical protection at the architectural scale while also supporting socio-ecological sustainability. Shaded pedestrian axes, public rooftop gardens, and green terraces provide thermal balance in areas of the city where heat stress is most intense. These areas increase biodiversity, adding new habitats to the urban ecosystem and enhancing users' interaction with nature (Hu et al., 2024). Therefore, green infrastructure is not only a means of climate protection but also a comprehensive urban improvement tool in terms of social inclusion and quality of life.

4.5. Conclusion: A Nature-Based Protective Design Paradigm

The architectural shield role of green infrastructure offers a nature-based protective design paradigm against the heat, flooding, air pollution, and energy crises faced by modern cities. This paradigm blurs the boundaries between architecture and landscape by positioning the building envelope as an extension of nature. Thus, the urban space becomes an active buffer system for both human and ecosystem health.

Future architectural applications must be based on green infrastructure strategies that simultaneously achieve not only technical efficiency but also biophysical resilience, ecological aesthetics, and climatic adaptation principles. Structures designed with this approach are now considered "living architectural organisms" that transform and protect the environment rather than being exposed to environmental conditions.

5. Adaptive and Flexible Design Approaches

Climate change, increasing temperature fluctuations, extreme rainfall, and periods of drought invalidate the concept of fixed and closed spaces, directing the disciplines of architecture and landscape design toward designing adaptive (adjustable) and flexible systems. Adaptive design refers to building forms that can perceive environmental variables and respond to them physically or functionally, and are therefore temporally, spatially, and climatically variable (Mahdavinejad et al., 2023). This approach is not merely a technological innovation; it is an ecological paradigm shift that brings dynamic processes in nature to the architectural scale.

5.1. Climate-Sensitive Architectural Systems

The fundamental principle of adaptive architecture is the direct integration of microclimate data into design decisions. Digital modeling tools developed in recent years—ENVI-met, Ladybug Tools, CFD (Computational Fluid Dynamics) analyses—simulate temperature, wind, humidity, and radiation distributions around the building with high accuracy and incorporate them into the design process (Wong & Jusuf, 2023). This allows architectural forms to be shaped not only by aesthetic criteria but also by biophysical parameters such as heat transfer, airflow, and shading optimization.

In such data-driven design processes, landscape systems become active components that support the environmental performance of the building. For example, the vegetation cover around the building creates a "living environmental envelope" that filters solar radiation, directs airflow, and provides cooling through evapotranspiration (Berardi & Ghaffarianhoseini, 2024). Such integrated design approaches, which address architecture and landscape together, increase the biophysical resilience of the urban microclimate.

5.2. Biomimetic and Nature-Based Adaptation Strategies

Another aspect of adaptive design is to incorporate nature's self-regulating mechanisms into structural systems by utilizing biomimetic principles (the imitation of biological forms and processes). For example, the ability of some plants to reduce evaporation by folding their leaf surfaces in response to water scarcity is being replicated in smart facade systems using photochromic or thermoactive materials (Cook et al., 2025). Similarly, plant-based shading structures (e.g., vine-supported pergolas, green roof shields) provide passive climate control by naturally responding to changing sun angles and wind regimes.

Biomimetic principles involve not only copying forms but also adapting the self-regulating logic of natural systems to the architectural scale. Therefore, modern adaptive architecture moves away from the static understanding of structures and aims to produce “living structures” that can renew themselves and are sensitive to ecological inputs (Kumar et al., 2025). This approach makes the dimension of time an essential component of design in architecture because it works in harmony with the constantly changing nature of the landscape.

5.3. Modular and Hybrid Design Systems

Adaptive design applications on a global scale rely on the combined use of modular systems at architectural and landscape scales. Modular elements offer flexible systems that can be modified, expanded, or reduced according to environmental conditions. For example, modular rain gardens or green roof panels can be designed to be adaptable in terms of water retention capacity and plant selection in different climate zones (Li et al., 2024). These systems offer the advantages of scalability and ease of maintenance in sustainable building production.

Hybrid systems represent intermediate solutions where architectural structures and landscape elements are integrated. For example, vertical water harvesting systems integrated into the load-bearing columns of buildings serve both structural and ecological functions. Similarly, vegetation integrated under photovoltaic canopies optimizes both energy production and microclimatic cooling. These hybrid approaches constitute concrete examples of architectural-energetic-ecological integrity (Sommese et al., 2024).

5.4. Flexibility, Resilience, and Change Over Time

The most defining feature of adaptive and flexible design is its capacity for change and renewal over time. This feature aligns with the concept of “succession” in landscape ecology. For a system to be truly resilient, it must not only be durable but also open to change (Cook et al., 2025).

Therefore, in architecture, open-ended systems that can be reshaped according to usage, climate, and environmental conditions are gaining prominence over rigidly programmed spatial concepts. For example, permeable facade panels dynamically contribute to user comfort by altering light transmission according to plant density. Similarly, automatic shading systems optimize both energy efficiency and thermal comfort according to changing rainfall and temperature scenarios. These applications demonstrate that adaptive architecture is not merely a design approach but an ecological way of thinking.

5.5. Future-aspect Perspective

Today's developing sensor technologies, artificial intelligence-supported modeling, and environmental data flows enable adaptive design to become proactive rather than reactive. These developments have brought the concept of Smart Green Infrastructure to the forefront; in these systems, building envelope and landscape components interact with meteorological data to provide real-time microclimate optimization (Berardi & Ghaffarianhoseini, 2024).

Thus, architecture is transforming into a discipline that not only references nature but also establishes a co-evolutionary relationship with it. This transformation places the principle of ecological design, "cooperation with nature rather than competition with nature," at the center of space production. Consequently, adaptive and flexible architectural-landscape systems can be defined as active, learning, and renewing ecological organisms for the cities of the future.

6. Sustainability and Ecosystem Services Perspective

Global environmental degradation has strained the carrying capacity of urban ecosystems, making the concept of ecosystem services (ES) a central component in the design approaches of architecture and landscape disciplines. Ecosystem services encompass the regulatory, supporting, provisioning, and cultural benefits that nature provides for human well-being (MEA, 2005). This approach demonstrates that sustainable architecture is not limited to energy efficiency or carbon reduction; it also aims to reintegrate natural processes into the urban ecosystem (Kumar et al., 2025).

6.1. Redefining Ecosystem Services at the Architectural Scale

Traditionally, architectural design focused on reducing the building's impact on the environment; current approaches redefine architecture as a system that produces ecosystem services. This paradigm shift views buildings not as "energy consumers" but as organisms that produce ecological functions (Cook et al., 2025).

For example, green roof and façade systems provide multiple ecosystem services, including not only thermal insulation but also carbon sequestration, air pollutant filtration, rainwater retention, noise absorption, and increased biodiversity (Berardi & Ghaffarianhoseini, 2024). These applications transform the building envelope from a mere physical boundary into an active ecological surface.

Similarly, permeable pavement systems, rain gardens, and bio-swales support the soil water cycle, reducing flood risk and contributing to the stabilization of groundwater levels (Li et al., 2024). Architecture thus becomes an ecosystem component that supports the continuity of the hydrological cycle.

6.2. Carbon Cycle, Energy Efficiency, and Microclimate Regulation

The built environment accounts for approximately 38% of global carbon emissions (IEA, 2023). Therefore, design decisions that balance the carbon cycle are one of the most critical aspects of sustainable architecture. Green infrastructure systems function as biological carbon sinks through photosynthesis, while also providing indirect carbon reduction by lowering energy demand (Tuğluer & Dönmez, 2022).

Research shows that green roofs and vertical greening systems can store an average of 1.5–3.0 kg C/m² of carbon per year (Kumar et al., 2025). In addition, these systems provide microclimatic moderation by reducing surface temperatures by 2–5 °C and reducing the cooling energy requirements of buildings by 20–25% (Santamouris, 2024). Thus, a symbiotic relationship is established between biotic (natural) and technological (structural) processes in terms of the energy cycle.

Furthermore, plant evapotranspiration reduces the heat island effect and increases thermal comfort by maintaining the moisture balance in the urban fabric. This microclimatic effect has become a measurable sustainability indicator not only at the individual building scale but also at the neighborhood and city scales (Wong & Jusuf, 2023).

6.3. Biodiversity, Habitat Quality, and Ecological Connectivity

Biodiversity is of fundamental importance for the continuity of ecosystem services (Çakır & Gül, 2024). Habitats fragmented by urbanization weaken the function of ecological networks, leading to a decline in carbon cycling, water retention, and air quality services (Hu et al., 2024). Therefore, preserving and enhancing ecological connectivity is essential in architecture and landscape planning.

Green corridors, ecological buffer zones, and modular green roofs create microhabitat continuity by providing passage and feeding areas for both plant and animal species. In particular, the selection of pollinator-friendly plants and the use of local species support the reestablishment of biotic balance in urban ecosystems (Raza et al., 2024). Thus, architectural and landscape design becomes part of an ecological network that supports a multispecies way of life, rather than being solely human-centered.

6.4. Cultural and Psychological Ecosystem Services

The cultural dimension of ecosystem services encompasses the psychological, aesthetic, and recreational benefits provided by nature. Green roofs, terrace gardens, and public green courtyards reduce stress levels, enhance cognitive performance, and strengthen social integration by offering city dwellers the opportunity to interact with natural elements (Raza et al., 2024).

Spaces developed in line with biophilic design principles bring the human-nature relationship to the center of the architectural experience through elements such as natural light, plant texture, the sound of water, and natural materials. This approach establishes a direct link between microclimatic improvement and human health and quality of life. Therefore, sustainable architecture is considered not only an ecological practice but also one that produces a psycho-social ecosystem service (Cook et al., 2025).

6.5. Sustainability Indicators and Measurement-Evaluation

The use of quantitative indicators has become important for monitoring ecosystem services in architecture and landscape design. Current research highlights the following parameters in sustainability assessments (Li et al., 2024):

- Carbon sink capacity (kg $C/m^2/year$)
- Evapotranspiration rate (mm/day)
- Surface temperature difference (°C)
- Rainwater retention capacity (L/m^2)
- Biodiversity index (Shannon-Wiener H’)
- Green space accessibility rate (%)

When measured in an integrated manner at the building and landscape scale, these indicators provide comparable data in terms of both energy balance and ecological performance. Thus, the concept of sustainability becomes not only a political goal but also a measurable ecological outcome.

Consequently, sustainability can be tangibly implemented through the production of ecosystem services, which is the common ground between architecture and landscape. In this context, nature-based architecture and green infrastructure systems simultaneously produce multidimensional ecosystem services such as carbon storage, water cycle regulation, microclimatic balancing, and biophilic quality of life. The sustainable cities of the future will be built on spatial systems that combine technological efficiency with ecological productivity and establish symbiotic relationships with nature.

7. Conclusions and Future Directions: Architecture-Landscape Integration For Resilient and Ecological Cities

The environmental, economic, and social impacts of climate change on a global scale have clearly demonstrated that the disciplines of architecture and landscape architecture must work not independently of each other, but within an ecological framework. Today, sustainability cannot be limited to energy efficiency or the selection of building materials; it also requires transforming the way cities relate to biophysical systems (Cook et al., 2025). In this context, architecture-landscape integration is becoming a key determinant of resilience and ecological adaptation capacity in the cities of the future.

7.1. Nature-Based Integrated Design Culture

The findings of this study show that Nature-Based Design approaches reorganize different systems, from the building scale to the urban scale, within an ecological integrity. Green infrastructure systems (blue-green corridors, permeable surfaces, green roofs, rain gardens) produce multiple benefits in terms of micro-climatic regulation, water cycle management, carbon sinks, and biodiversity (Sommese et al., 2024; Li et al., 2024). This multifunctionality necessitates an ecosystem-based evaluation paradigm, distinct from the singular performance metrics of traditional architecture (thermal insulation, energy savings, etc.).

The future culture of architecture and landscape should adopt a cooperative approach that works with nature rather than imitating it. Building envelopes, surfaces, and landscape elements should function as ecological interfaces that support natural processes (evaporation, filtration, photosynthesis, carbon sequestration). This transformation represents a new biophysical design approach that combines ecological aesthetics with engineering performance.

7.2. Climate Adaptation and Resilience Perspective

Models developed to reduce the vulnerability of cities to climate change place coordination between architecture and landscape at the center of resilience strategies. Adaptive and flexible architectural systems offer dynamic structures that can respond to environmental inputs and change their form and function according to climatic conditions (Mahdavinejad et al., 2023). Similarly, green infrastructure networks enhance ecosystem resilience by regulating the carbon, water, and energy cycles of the urban system (Kumar et al., 2025).

The synergy between these two scales—building and landscape—creates the multi-layered nature of ecological resilience. At the building scale, this is achieved through material selection, envelope permeability, and orientation; at the landscape scale, it is supported by ecological connectivity, habitat continuity, and surface permeability. The resulting integrated system offers optimal resilience in terms of both adaptation to climatic shocks and the capacity to absorb environmental stresses.

7.3. Digitalization, Data-Driven Planning, and Smart Green Infrastructure

Over the past five years, climate data-based design and digital simulation technologies have created new opportunities in architecture-landscape integration. Real-time environmental data (temperature, humidity, wind, CO_2 concentration) and sensor-based monitoring systems have made it possible to measure the performance of green infrastructure (Berardi & Ghaffarianhoseini, 2024). This has brought the concept of "smart green infrastructure" to the forefront.

Smart green infrastructures monitor and optimize natural processes with digital systems, enabling data-driven decision-making. In these systems, AI-supported models automatically control irrigation, shading, or airflow adjustments based on environmental feedback. These developments combine nature-based solutions with smart city technologies, ensuring that "ecological information systems" become an integral part of urban design.

7.4. Policies, Legislation, and Implementation Strategies

For the effective implementation of architecture-landscape integration, ecological design must be reflected in legal and administrative frameworks. The European Green Deal (2020) and the United Nations Sustainable Development Goals (SDG 11: Sustainable Cities and Communities; SDG 13: Climate Action) form the global political basis for this integration.

In the context of Turkey, the "Climate Change Adaptation Strategy and Action Plan (2023–2030)" recommends the development of blue-green infrastructure networks, the integration of nature-based design principles into urban planning, and the inclusion of microclimate analysis requirements in building permit processes. These regulations have the potential to create a systematic transformation not only in environmental protection but also in the culture of architectural production.

7.5. Future Directions and Research Priorities

Future research should deepen the integration of architecture and landscape in the following directions:

1. Ecosystem-based carbon management: Quantitative modeling of carbon storage capacity in building and landscape systems.

2. Biodiversity performance indicators: Evaluation of the potential of architectural surfaces to function as habitats.

3. Urban microclimate scenarios: Long-term thermal comfort simulations based on climate change projections.

4. Integrated indicator system: Digital data platforms that evaluate energy, water, carbon, microclimate, and social indicators together.

5. Social participation and ecological literacy: Collaborative production models that increase user awareness in ecological design processes.

These approaches will ensure that the ecological cities of the future are sustainable not only technologically, but also socially, aesthetically, and ethically.

8. Conclusion

The effects of global climate change on cities are clearly pushing the limits of traditional planning and architectural approaches. Increasing heat waves, irregular rainfall patterns, floods, and heat island effects threaten not only the socioeconomic but also the biophysical resilience of cities. In this context, it has become imperative for the disciplines of architecture and landscape architecture to move beyond operating as two separate fields and be redefined within a common ecological framework.

The theoretical and practical approaches discussed in this study reveal that nature-based planning and design have multidimensional effects on microclimatic balance, water management, the carbon cycle, and ecosystem services in cities. Green infrastructure systems in particular—green roofs, permeable surfaces, rain gardens, green corridors—serve not only an aesthetic function but also a functional climatic protection mechanism in the urban ecosystem. These systems reduce surface temperatures, improve air quality, regulate the rainwater cycle, and increase carbon sink capacity (Kumar et al., 2025; Li et al., 2024).

At the architectural scale, adaptive and flexible design approaches make it possible to create dynamic structures that respond to climatic variations and interact with environmental data. This approach represents the spatial counterpart of ecological systems that evolve over time, rather than the production of static spaces (Mahdavinejad et al., 2023). Adaptive designs not only enhance energy efficiency but also emulate nature's self-regulating processes—such as evapotranspiration, photosynthesis, and water filtration—thereby generating a biomimetic ecological performance.

From the perspective of landscape architecture, ecological connectivity and habitat continuity have become among the most critical indicators of sustainable urban structure. Green corridors, buffer zones, and modular green surface systems support urban biodiversity and ensure the continuity of ecosystem services (Hu et al., 2024). These systems are not merely tools for environmental protection; they are spatial strategies that enhance human well-being, thermal comfort, and overall quality of life.

Within the framework of sustainability, the integration of architecture and landscape transforms the production of ecosystem services into a direct design output. This approach envisions cities that are not only resilient to the climate crisis but also regenerative, capable of restoring and reproducing natural systems. Thus, the architecture of the future must be designed not as a system that consumes the environment but as one that actively regenerates it. At this point, the concept of “green” ceases to be an aesthetic label and becomes an expression of biophysical functionality. In conclusion, the most critical step in building sustainable cities is the convergence of architectural and landscape disciplines around a nature-based, data-driven design paradigm that prioritizes the generation of ecosystem services. This paradigm envisions living cities, where buildings and open spaces operate synergistically and where the energy, water, and carbon cycles are managed through ecological principles guided by climatic data.

This integrated understanding unites the formal aesthetics of architecture with the ecological functionality of landscape, thereby redefining the city as not merely a consumer of nature but an active component of it. Such a transformation establishes the guiding principle of the sustainable cities of the future: “Designing with nature, rather than imitating it.”

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This book chapter was written by a single author, and there are no conflicts of interest to declare.

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